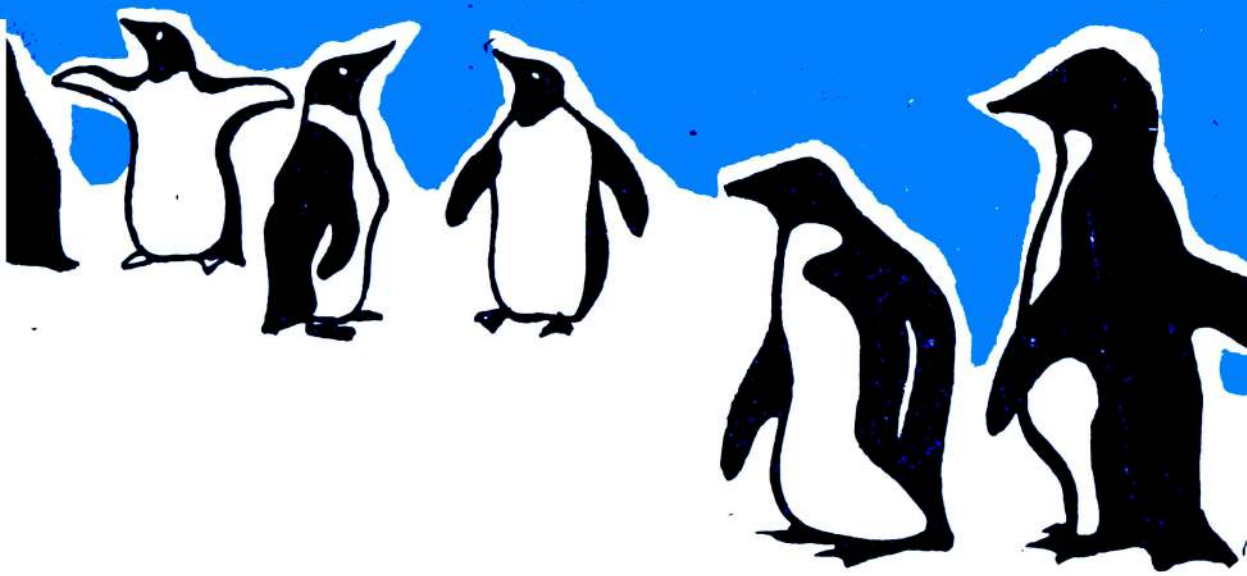
V. LEBEDEV

ANTARCTICA



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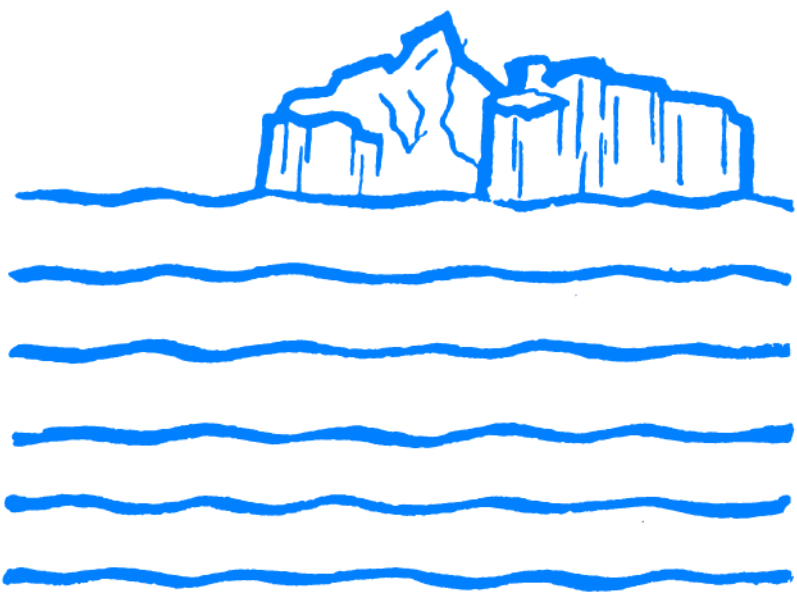

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INTRODUCTION

More than one hundred years have elapsed since the discovery of the Antarctic shores by the expeditions of Faddei Bellingshausen, Mikhail Lazarev, Eduard Bransfield, Nathaniel Palmer, John Biscoe, Dumont d'Urville, Charles Wilkes and James Ross. And although many an outstanding explorer has sought to unveil the mysteries of these South Polar regions, very little is known of their well-nigh inaccessible interior.

"At the bottom of this planet lies an enchanted continent in the sky, like a pale sleeping princess," the late Admiral Richard E. Byrd wrote in 1947. "Sinister and beautiful she lies in her frozen slumber, her billowy white robes of snow weirdly luminous with amethysts and emeralds of ice, her dreams iridescent ice halos around the sun and moon, her horizons painted with pastel shades of pink, gold, green and blue.

"Such is Antarctica.... The ice-imprisoned continent covers almost 6,000,000 square miles of the earth's surface—nearly as much as South America. Most of the interior actually is less known than the sunlit side of the moon."

The American explorer's picturesque admission that the interior of the Great Southern Continent was known less than the surface of the moon was, until recently, very widely reflected in scientific literature.

Rich in minerals and whaling and sealing opportunities, Antarctica and the Southern Ocean are of great interest

to science, especially those branches linked with geography and geophysics, and to the world's economy.

This vast expanse south of the man-conquered lands first attracted attention many centuries ago, and the early charts of the Terra Australis Incognita appeared at the turn of the 16th century. The Antarctic waters, it is possible, were first visited by Amerigo Vespucci in 1502 when his expedition approached South Georgia Island, but it was more than three centuries later that Antarctica's shores and shelf-ice were discovered.

Whether this land is a continent or an archipelago remains a mystery to this day.

The first scientists landed in Antarctica at the turn of this century and since then the continent and the seas between have been visited by more than 150 scientific expeditions and numerous military, sealing and whaling parties.

Research work in this part of the world has solved a number of problems ... and set the scientists a lot of new ones. Of the latter two are of utmost importance, for they have completely upset all conceptions regarding the character of the rock-floor of the continental ice-sheet and its thickness. Until quite recently it was believed that the continent was divided in two by a strait connecting the Weddell and Ross seas. This was partially refuted by U.S. air reconnaissance results: in 1947 the Americans discovered land beyond the Lassiter Shelf-Ice and in 1955 a mountain range 160 kilometres south of the Filchner Barrier (southwestern and southeastern parts of the Weddell Sea).

The results of seismic soundings carried out in East Antarctica by the Norwegian-British-Swedish (1949-52) and Soviet (1956-57) expeditions unexpectedly revived the "continent or archipelago" argument. These soundings, undertaken in long. 10°W. and long. 93°E., 620 and 375 kilometres off the Antarctic coast, offered no convincing proof that the edge of the continent had been reached.

In the first case, at 550 kilometres, the Antarctic sheet was more than 2,000 metres thick, and in the second, at 375 kilometres, it was upwards of 3,000 metres. At the first point the rock-floor of the ice-sheet was more or less at sea-level and at the second, several hundred feet below it.

Interesting results were likewise obtained by seismic soundings undertaken by American scientists in West Antarctica. Carried out on a 520-mile stretch from long. 150°W. lat. 80°S. to long. 120°W. lat. 80°S., they showed that the rock-floor of the Antarctic shield was 1,500 metres below sea-level and that 540 kilometres off the coast (long. 120°W., lat. 80°S.) the ice-sheet was 3,000 metres thick.

Perhaps one of the most important geographical tasks today is to determine whether Antarctica is a continent or an archipelago. The solution of this hypothetic question will explain the causes and dynamics of major climatic changes on the earth, the enigma of the continent's Paleozoic landscape and the accumulation of thick ice masses in the interior far from the known boundary of the Southern Ocean. In these days of technological achievements, the unveiling of the mystery of Antarctic paleoclimatology will make it possible to prepare long-term synoptic charts and facilitate man's conquest of Nature. Finally, the solution of this question will enable us definitely to determine the thickness of the continental ice-sheet.

Another moot question is whether the Antarctic waters are all part of the Southern Ocean, and how to delineate its geographic boundaries.

The waters encircling Antarctica are much better known than the continent itself, and that is due chiefly to whaling and navigation. But our knowledge of the Southern Ocean is also too inadequate to satisfy the all-round requirements of science. Formation of bottom water, deep water circulation, thermal interaction of the waters and the ice continent, atmosphere and warm lat-

itudes of the ocean—these questions have been solved only partially and, chiefly, qualitatively. Forming in the south polar regions and then flowing to the subtropics of the Northern Hemisphere, the Antarctic waters are a powerful transmission link in the thermal counteraction of climatic zones.

According to W. L. Stokes' ice theory, published in 1955, thermal interaction along the Antarctic Sheet-Southern Ocean-Pacific Ocean line is a process determining the development and culmination of glacial epochs on the earth.

It is now generally recognized that man's utter lack of knowledge of atmospheric circulation over Antarctica is one of the reasons why no synoptic weather charts for Europe can be drawn for a period of ten or twenty years. Pressure, temperature and circulation charts worked out for the south polar regions are based almost exclusively on theory and have not been checked in practice.

The International Geophysical Year (1957-58) has ushered in a new phase in the study of Antarctica. There are about fifty research stations (including six Soviet) now operating on the continent and the offshore islands; many countries are also doing research work in the Antarctic waters.

The Soviet expedition left for Antarctica in November 1955 and set up its first scientific base, Mirny, on February 13, 1956. Other countries taking part in the IGY are the United States, Britain, France, Norway, Australia, New Zealand, Argentina, Chile, Japan and Belgium, with the German Federal Republic expected to join in later on.

ANTARCTIC'S BOUNDARIES

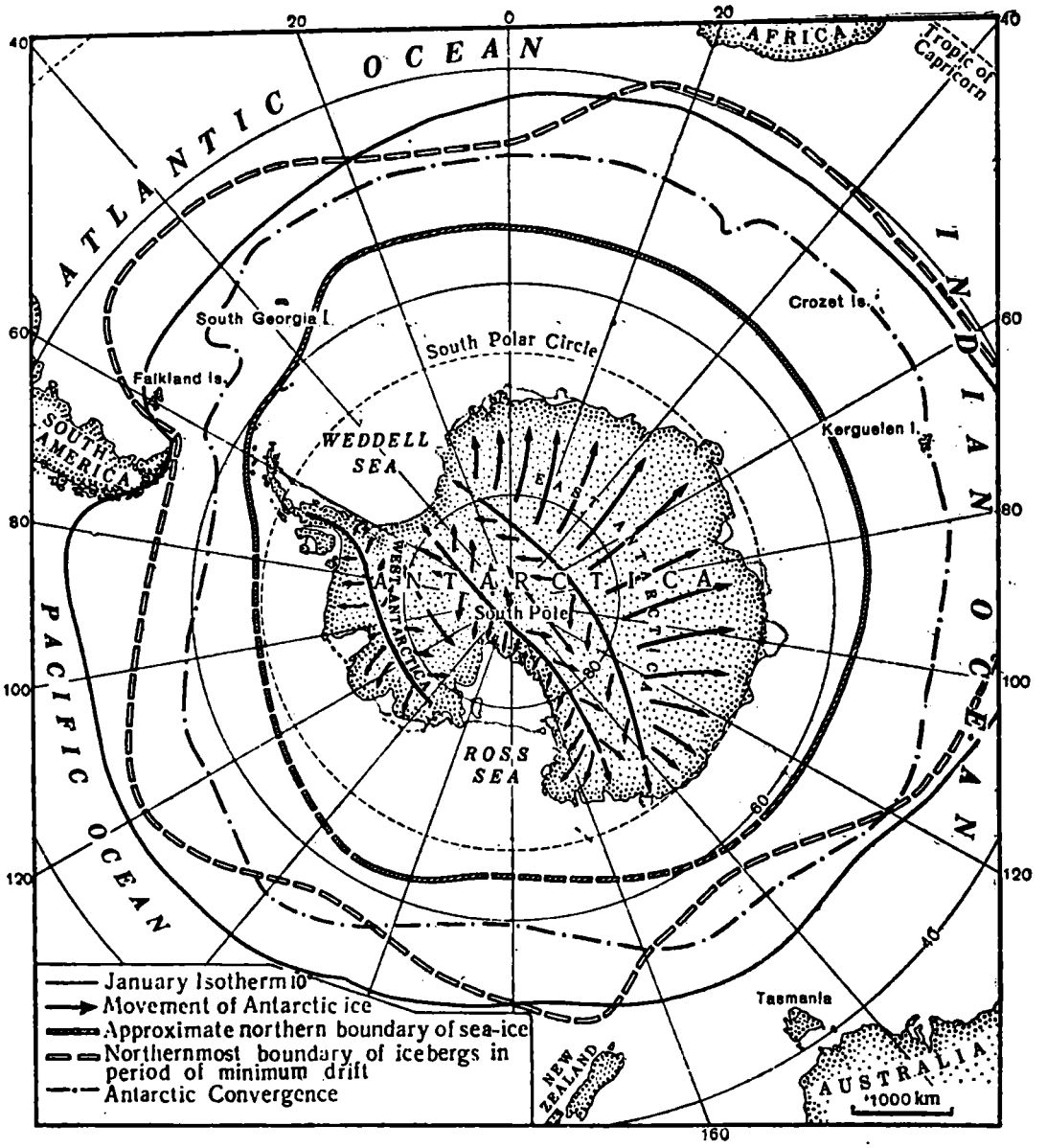
Antarctic (from the Greek "Antarktikos," meaning opposite to the Arctic) was the name originally given to Enderby Land on the coast of the south polar continent.

Its boundary is an arbitrary one. Some claim that it runs along the 50th Parallel, others—along the 55th, still others—along the 60th or within the Antarctic Circle (lat. 66°30′S.). The polar day and night, the sun's low position over the horizon, land- and sea-ice formation, the cold temperature of the water, the absence of flowering plants, and low temperature in summer—all these traits distinguish the Antarctic region sharply from the adjacent regions.

Moreover, each latitude has its own features. In the Southern Hemisphere, once a year in 66°S. the sun does not set for 24 hours, while in 68°S. it does not rise for the same length of time. A degree to the north of these latitudes, the sun does not rise and set for 22 hours at a time, while in 70°S. the polar day lasts 64 days and the polar night—59.

Sea-ice spreads farthest north during the southern spring and its edge in September (in about 59°S.) is often taken for the Antarctic's boundary. What is ignored, however, is that the northernmost boundary of the icebergs, even in the period of their minimum drift, passes north of the ice boundary.

The cold climate, with the January isotherm of 50°F., spreads farther down to the lower latitudes, to 38°S., covering in the Southern Hemisphere a territory 2.7 times



Antarctica's natural boundaries and movement of ice (the latter after O. S. Belov, 1957)

greater than in the Northern (68,840,000 square kilometres).

The low temperature of the Antarctic's surface water and its salinity are due to ice and climatic conditions. It flows northward and then sinks and gives way to lighter and warmer water in the lower latitudes. This occurs at the Antarctic Convergence, a clearly defined sinuous boundary circling the continent in 48° to 62°S. The posi-

tion of the convergence is very steady, varying from season to season and from year to year at most by 1°30′.

Henceforth, we shall regard the Antarctic Convergence as the Antarctic's boundary and the total area of the region as 51,900,000 square kilometres.

To a certain degree this boundary is conventional and has its proponents and opponents in Soviet polar literature. Climatologist B. P. Alisov (1950) and physicogeographer K. K. Markov (1957) claim it passes along the Antarctic Front, while oceanologist V. K. Buinitsky (1953) and climatologist G. M. Tauber (1956) say it follows the Antarctic Convergence.

In fact, Buinitsky says the Antarctic Convergence is "Antarctica's natural boundary," for it is there that the temperature and salinity of the surface water, as well as the range of planktonic organisms, undergo sharp changes (V. Buinitsky, *Antarctica*, Moscow, 1953).

Tauber, who has been to Antarctica with three expeditions and is the author of a new chart of the Antarctic Front, agrees that the Antarctic's boundary passes along the Antarctic Convergence. "There is every reason for believing that," he writes, "inasmuch as it provides for a whole complex of physicogeographical factors" (G. M. Tauber, *Antarctica*, Moscow, 1956, p. 7).

Geographically, the character of the region south of the Antarctic Convergence is determined by common glacial traits. Still in the glacial epoch, as it were, it is a region entirely covered by a sheet of ice and ice-freshened ocean water. The layer of this water in the Southern Ocean, when melted, is about one metre deep.

The existence of different atmospheric fronts, in our opinion, does not create dissimilarity in the nature of various Antarctic regions, for besides air circulation a big role is played by deep water circulation.

The January isotherm of 10°C. shows that there is no place in the Antarctic region where the climate is warmer than that of the tundra. And nowhere can there be any flowering plants despite the fact that some of the northern Antarctic islands are closer to the equator than Moscow is.

The iceberg boundary also passes north of the Antarctic Convergence and that is why one comes across bergs in every part of the Antarctic and at any time of the year.

Sea-ice does not approach Antarctica's boundaries and covers only 22,600,000 square kilometres, that is, only six-tenths of the area of its waters.

DISCOVERIES AND EXPLORATION IN SOUTH POLAR LATITUDES

There is no proof that any of the aborigines of the Southern Hemisphere had penetrated into the south polar regions before the Europeans, although the similarity in the languages of the tribes inhabiting East Australia, Patagonia and Tierra del Fuego permits to assume that in ancient times they did migrate by way of the Antarctic islands. As far as it is known, however, there is no archaeological data to back this assumption.

It is considered quite likely that the south polar regions were first reached in 1501-02 by a Portuguese fleet commanded by Admiral Fernao de Noronha. His ships, possibly, approached South Georgia Island in 1502, but it is difficult to prove that Noronha's expedition discovered this land because, as was often the case before the chronometer was invented, the geographical longitude was given only approximately. Moreover, some scientists hold that the location of this island was given deliberately wrong on account of the Spanish-Portuguese agreement to divide the world along long. 46°W. Hence the assumption that the Portuguese actually saw the Falkland Islands or perhaps Tierra del Fuego and not South Georgia.

The description of the island, on which modern science bases its assumption and which was summarized from the letters of one of the participants in Noronha's expedition, the Florentine astronomer and merchant Amerigo Ves-

pucci, fits in perfectly with South Georgia's nature, size and location. Vespucci claimed that the ships sailed from the South-American Bay of Canea (lat. 25°S., long. 48°W.) in a southeasterly direction. On April 3, 1502, "we found ourselves so high that the southern pole stood quite 52 degrees above our horizon.... And we were already at a distance of full 500 leagues[1] southeast from the harbour whence we had set out.... On the seventh day of April we had a night which was 15 hours long.... We had sight of a new land along which we ran for about 20 leagues, and found that it was wholly a rocky coast[2]: and we beheld therein neither any harbour nor any people because, as I believe, of the cold which was so intense that no one in our fleet could fortify himself against it or endure it.... One ship could hardly see another for the great billows that were running and for the blinding mist.... We agreed with the Admiral ... that we should abandon land and turn round in the direction of Portugal" (E. W. Hunter Christie, *The Antarctic Problem*, London, 1951, p. 30).

Influenced probably by ancient Greek geography, 16th-century European scholars were of the opinion that there was a huge unknown continent south of the equator. This opinion was confirmed in a way by the discovery by Ferdinand Magellan of the rocky Tierra del Fuego in 1520. Incidentally, the story about the Terra Australis Incognita in the temperate latitudes of the Southern Hemisphere was at times nurtured by absolute myths. Camille Vallaux says that in his report on the voyage to the New Indies in 1503-10 Captain Gonneville charted a vast continent in the Atlantic south of 50°S., describing it as "a fertile land with a temperate climate and inhabited by

[1] E. W. Hunter Christie says in this case a league is equal to four miles (*The Antarctic Problem*, London, 1951).

[2] South Georgia is a big mountainous island, 100 miles in length and 20 in width, stretching from northwest to southeast in 35°44′-38°17′W. Its northernmost point is in 53°57′S.

timid and sociable people" (C. Vallaux. *Geography of Seas*, p. 93, Russ. Edition). On the map drawn up by Gerhard Mercator in 1587, the Southern Continent extended from the Pole to all the regions in the southern latitudes then unknown to navigators. In the Pacific and Indian oceans this continent extended into the tropics and merged with Tierra del Fuego in the Atlantic.

Such conceptions about the Southern Continent were stubbornly defended and theoretically substantiated by the proponents of "speculative geography" as late as the 18th century. They claimed, for instance, that the distribution of continents was subject to the law of balance, that is, there had to be a continent in the Southern Hemisphere equal in size to the northern continents and the sea and land masses in both hemispheres had to be equal in size too. The last champion of this theory, Alexander Dalrymple, said in the 1760's that all the lands discovered south of 40°S. were in fact the extremities of the Southern Continent. The first phase of James Cook's study of the Antarctic revealed, however, that the greater part of this region was an open sea.

In 1578, Sir Francis Drake's squadron sailed through the Strait of Magellan into the Pacific Ocean, by-passed Tierra del Fuego from the west and discovered, according to Fletcher, one of the participants in the expedition, that "the uttermost part of the land towards the South Pole, which is the uttermost cape or headland of all these islands, stands in the 56th degree, without which there is no main nor island to be seen to the southwards; but the Atlantic Ocean and the South Sea meet in large and free scope (E. W. Hunter Christie, *The Antarctic Problem*, London, 1951, p. 38). Earlier still, in 1526, the sea south of Tierra del Fuego, was probably seen by the Spaniard Hoces (James Cook, *A Voyage towards the South Pole and Round the World*).

Sailing off Antarctica in 1592, Captain John Davis (England) discovered the strategically important Falk-

South Georgia Island (E. W. Hunter Christie, 1951)

land Islands, which became the object of a dispute between Spain, France and England in the 18th century, between England and Germany in the two world wars, and between England and Argentina after World War II.

In 1603, a Spanish war vessel reached 64°S. in the region of Drake Passage and, possibly, the South Shetland Islands.

In 1615, Dutch navigators Schouten and Le Maire sailed through what later became known as Le Maire Strait and Drake Passage into the Pacific, and skirted Tierra del Fuego from the south, calling its southern extremity Cape Horn after one of the ships of the expedition.

In 1675, La Roche, an English merchant of French birth, sailed through Drake Passage into the Atlantic where his ship was caught in a storm and carried away to the coast of South Georgia. The vessel remained in a bay for four-

teen days, and La Roche was the first to describe the island's coast.

In 1738, Bouvet de Lozier, a French navigator, sailed in two ships for the South Atlantic to search for Gonneville Land. On January 1 of the following year the seamen beheld a high ice-covered island in 54°S., which they took for the southern extremity of the Southern Continent and named it Cape Circoncision (now Bouvet Island). Only five miles long, it is usually covered with a mist and that may explain why the French claimed it was big in size.

In 1772, another French navigator, I. J. de Kerguelen-Trémarek, set out to find Gonneville Land and discovered instead an island which was named after him. He had mistaken it for the southern part of the continent. Four years later this island was visited by Cook who called it "Isle of Desolation."

In 1772-75, Cook sailed in the *Resolution* and the *Adventure* around the south polar region, keeping most of the way close to 60°S. and proving for the first time that there was no continent in the temperate latitudes. Cook was an opponent of "speculative geography" and a personal enemy and rival of Dalrymple, one of the staunchest champions of this trend and a claimant to the leadership of the English expeditions sent to discover the Southern Continent. Perhaps that is the reason why Cook issued a statement challenging the validity of the Southern Continent theory.

"I had now made the circuit of the Southern Ocean in a high latitude," he said, "and traversed it in such a manner as to leave not the least room for the possibility of there being a continent, unless near the Pole, and out of reach of navigation.... A final end [is thus] put to the searching after a southern continent" (James Cook, *A Voyage towards the South Pole and Round the World,* p. 440).

The "speculative geography" theorizers, whom Cook had attacked in a report on his return, spread a new myth that there was no land in the south polar regions. Cook himself had no part in concocting this legend. Reporting on his voyage, he wrote: "That there may be a continent, or large tract of land near the Pole, I will not deny; on the contrary, I am of the opinion that there is; and it is probable that we have seen a part of it.[1] The excessive cold, the many islands and vast floats of ice, all tend to prove that there must be land to the south."

James Cook

In the sections "Reasons for There Being Land About the South Pole" and "Conjectures Concerning the Formation of the Islands" Cook adduced three arguments to prove that there was a polar continent: low temperature, uneven extension of ice and formation of icebergs.

Analyzing the distribution of temperatures and the properties of ice-floes, Cook tried to outline the form of this polar land. "Very few ships have met with ice going round Cape Horn," he wrote, "and we saw but little below the sixtieth degree of latitude, in the Southern Pacific Ocean. Whereas in this ocean [Atlantic—*V. L.*] between the meridian of 40°W. and 50° or 60°E., we found ice as far North as 51°." In another place he said that in the Pacific "the mercury in the thermometer seldom fell so low as the freezing point, till we were in 60° and up-

[1] Cook meant the South Sandwich Islands, some of which he saw and took for a land mass, calling it Sandwich Land.

wards; whereas in the others, it fell as low in the latitude of 54°. This was certainly owing to there being a greater quantity of ice, and to its extending farther to the North, in these two seas [Atlantic and Indian Oceans—*V. L.*] than in the South Pacific; and if ice be first formed at, or near land, of which I have no doubt, it will follow that the land also extends farther North."

Moreover, assuming that the south polar land was the source of icebergs, Cook correctly described certain features of the nature of the continent he had never seen. It is, he wrote "a country doomed by Nature never once to feel the warmth of the Sun's rays, but to lie buried in everlasting snow and ice.... The valleys are covered, many fathoms deep, with everlasting snow; and, in the sea ... ice-islands are formed; ... from consolidated snow and sleet, which is, almost continually, falling or drifting from the mountains, especially in the winter.... During that season, the ice cliffs must so accumulate as to fill up all the bays, be they ever so large. This is a fact which cannot be doubted as we have seen it so in summer [on South Georgia—*V. L.*]."

Cook was quite right in presuming that the form of the bergs breaking off the glaciers depended on the character of the terrain. Icebergs, he said, "such as have a flat, even surface, must be of the ice formed in the bays, and before the flat valleys; the others, which have a tapering, unequal surface, must be formed on, or under, the side of a coast composed of pointed rocks and precipices, or some such uneven surface."

Claiming that the south polar lands were inaccessible, the British explorer wrote: "The risk one runs in exploring a coast in these unknown and icy seas is so very great, that I can be bold enough to say that no man will ever venture farther than I have done; and that the lands which may lie to the south will never be explored."

Cook's report about the abundance of seals on South Georgia was a signal for enterprising sealers. As far as

it is known, the first sealing vessels sailed for this island some time between 1775 and 1778. From 1800, sealing expeditions to South Georgia became regular affairs and the rich seal rookeries were quickly destroyed. A Fur Seal skin brought as much as $7 in 1819[1]. Nine years earlier, F. Hasselbourgh, captain of a British sealer, discovered Macquarie Island and it took only five years for its rich rookeries to be annihilated.

It was at about the time the Fur Seals were destroyed on South Georgia that William Smith, captain of the merchantman *Williams*, discovered the South Shetland Islands (February 19, 1819). In September of that same year the Spanish war vessel *San Telmo* was wrecked in a storm south of Cape Horn and Smith found the derelict off Livingstone Island in the South Shetland group when he hoisted the Union Jack there in October.

The British Crown considered this discovery of major strategic importance, for the possession of this island group gave it control over Drake Passage, and chartered the *Williams* for an official military hydrographic expedition to the islands under Eduard Bransfield. The vessel sailed from Valparaiso on December 19, 1819, and reached her destination on January 16, 1820.

It was at about this time, too, on December 27, 1819, that the Russian Antarctic expedition aboard the vessels *Vostok* and *Mirny*, under the command of Faddei Bellingshausen and Mikhail Lazarev, arrived at South Georgia. Their task was to make discoveries "as close as possible to the South Pole" (F. Bellingshausen, *Double Quest in the Antarctic Ocean and Voyage Round the World in 1819-21*, Moscow, 1949, p. 42). Bellingshausen was instructed by the Ministry of Marine to explore South Georgia and Sandwich Land, then "to keep as far south as possible," to exert "every effort and do everything to approach the Pole as close as possible while discovering un-

[1] More than one million Fur Seals were killed on South Georgia within a brief period.

F. F. Bellingshausen

known lands" and not to give up "this enterprise unless confronted by unsurmountable obstacles." The instructions further said: "If at the first meridians on your voyage south your efforts prove fruitless, you must renew your attempts" and repeat them "every hour in an effort to discover new lands and approach the South Pole." The two vessels were also ordered to circumnavigate the Earth.

Bellingshausen's flagship *Vostok* displaced 900 tons and was 39 metres long and 10 metres broad. The *Mirny* (530 tons) was 36 metres long and 9 metres broad. It may thus be seen that these two ships were about the size of the present-day whalers (average length—40 metres, tonnage—500). There were 117 men aboard the *Vostok* and 72 aboard the *Mirny*, among them astronomer I. M. Simonov, professor of Kazan University, and painter P. N. Mikhailov, member of the Academy of Fine Arts.

After exploring the southern coast of South Georgia at the end of December 1819, the Russian expedition set off for "Sandwich Land," discovering Zavodovski, on which they landed, and Leskov and Visokoi Islands on January 3-4, 1820. A few days later the two ships approached "Sandwich Land" and Bellingshausen discovered a number of islands which Cook had mistaken for capes, leaving the names given them by the English explorer. The Thule Coast discovered by Cook turned out to be a group of three islands. One of them Bellingshausen

named after Cook, and the one next to it was christened Bellingshausen Island by the British "Discovery II" expedition in 1930.

Bellingshausen left the name "Sandwich" to the group of islands he explored, calling them the South Sandwich Islands.

M. P. Lazarev

Continuing southeast, the Russian vessels crossed the Antarctic Circle on January 27, 1820, and on the following day became the first in the history of navigation to approach Antarctica's ice barrier in the region of Princess Martha Land.[1] Poor visibility and snow prevented Bellingshausen from realizing that he was before a vast expanse of ice-encumbered land. The mariners first took the ice off the Antarctic coast for white clouds. Here is how Bellingshausen himself described this on January 28: "'Continuing our voyage south, we encountered this noon at lat. 69°21′28″, long. 2°14′50″ [W.—*V. L.*] mases of ice that looked like white clouds in the falling snow."

Two miles farther southeast the navigators saw that this was "a solid stretch of ice running from east through south to west." Their way lay "straight to this hummocked ice field."

The *Vostok* was then in 69°25′S., 2°10′W., that is, if one judges by the South Polar Chart published by the Hydrographic Department in London in 1949, not more than

[1] This was the name given by the Norwegian Antarctic expedition of 1929-30, who were the first to visit these places after Bellingshausen and the first to photograph the coast from the air.

30 miles away from the Antarctic coast. According to the Navigation Chart of Antarctica published in Moscow in 1955 (Scale 1:3,000,000), this point lies 47 miles off the continent's coast and 20 miles off the present-day outer ice margin (in Bellingshausen's day this was apparently farther north).

The January 28 entry in Bellingshausen's diary makes no further mention of the ice field. Lazarev, on the other hand, enjoyed better visibility on that day in 69°23′S. and wrote that the evening was "fine." From the masthead of the *Mirny*, he said in a letter to A. A. Shestakov, he could see "*matery*[1] ice of extraordinary height stretching out as far as the eye could see." This unusual picture of continental ice, he added, was "a thrilling spectacle" (*Russian Discoveries in the Antarctic*, Moscow, 1951, p. 23).

On March 20, 1948, the Soviet *Slava* whaling flotilla, commanded by Alexei Solyanik, approached the continent in this same region. At 6 p.m. the ships were in 69°10′S. "The sky was clear, visibility excellent and our crews," Tauber wrote, "could see the coastline and mountains as far as 50-70 miles in the interior...."

In the Soviet Union, January 28 is marked as the anniversary of Antarctica's discovery. And in this connection it would be fitting to pay tribute to Lazarev, who captained the sloop *Mirny*, for the part he played in its discovery.

The *Mirny* and *Vostok* approached the continent for the second time five days later—at 2 a.m. on February 2, 1820—but on this occasion in 69°25′S., 1°11′W. Due to the high latitude, the sun was over the horizon. The mariners saw "up to fifty different-sized ice giants in the ice field" to the south. According to the above-mentioned British South Polar Chart, the *Vostok* was then between eight

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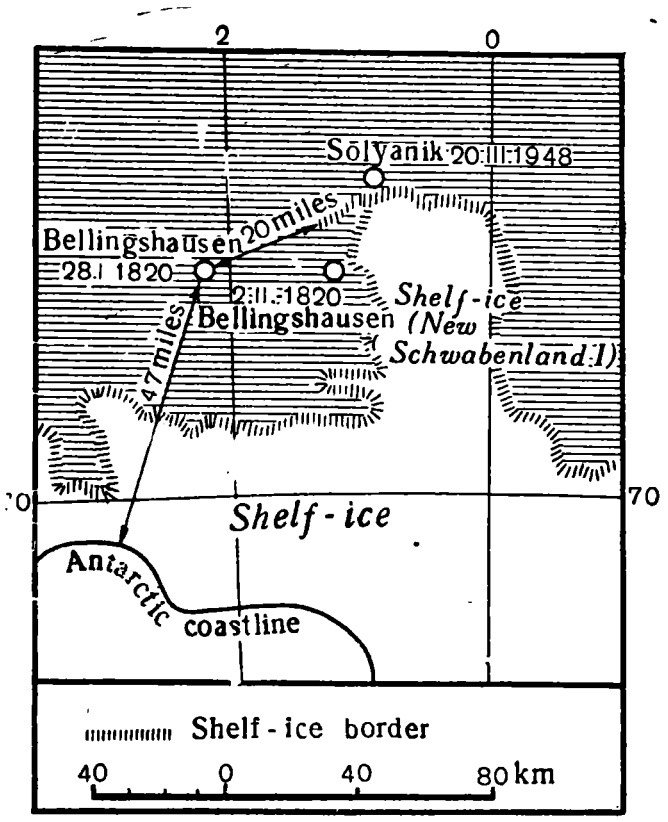
[1] The word *matery*, now somewhat out of use, has several meanings in Russian: continental (archaic), huge, basal, etc.

and ten miles off the New Schwabenland-I Shelf-Ice, and only 2.5 miles by the Soviet Navigation Chart. Bellingshausen's diary says visibility up to 6 p.m. on that day was very good[1]. "The wind was light, blowing from SOtO[2] and the weather fine as we continued our voyage southward," "the air was dry," "weather today was fine and dry (such as we had not had since sailing from the South Sandwich Islands)," "at six o'clock clouds covered the sky." There are indications that the seamen were instructed to observe the horizon at this point: "The eastern, southern, and western boundaries of this field stretched so far they were not visible."



Bellingshausen's and Solyanik's vessels off Princess Martha Land (after the Antarctic Navigation Chart, 1955)

The *Vostok*'s masthead was apparently 30 metres above water and for that reason a barrier about 30 metres high[3] should have been seen on the horizon over pack-ice from a distance of 16 miles, even if we do not take polar

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[1] Very good visibility is when one can see something as far as 27 miles away, good visibility—up to 11 miles, medium visibility—up to 5 miles, and poor visibility—up to 1 mile.

[2] Approximately 124°.

[3] The New Schwabenland-I Shelf-Ice is between 21 and 37 metres high and about 55 kilometres wide.

refraction into consideration. From a distance of eight or ten miles, the whole of the barrier should have been seen from the masthead; from the bridge—the top 12 to 20 metres.

The sun was in the southeast, low over the horizon, and the silhouette of ice barrier should have been seen clearly. It would be hard to believe that the seamen, instructed to observe the horizon, missed the barrier. Bellingshausen's entry in the diary, which may be taken as an indication that there was an ice barrier, speaks of "up to fifty different-sized ice giants." These were possibly the ice-tongues that break off the shelf-ice to form ice-bound bergs.[1]

Sailing in the upper latitudes, Bellingshausen's and Lazarev's vessels once again approached the continent 15 days later, on February 17, this time in 69°6′24″S., 15°51′45″W. Both on that and on the following day they were in the immediate vicinity of the shelf-ice fringing Antarctica in the region of Princess Ragnhild Land and Princess Astrid Land. The southernmost point reached by the *Vostok* then was apparently in 69°7′30″S., 16°15′W.

At about noon on February 17, Bellingshausen made the following entry in his diary: "The ice to the SSW merges with solid mountainous ice whose perpendicular walls form bays and surface slopes upwards towards the south to a distance so far that its end is out of sight even from the masthead."[2]

For two days the Russian vessels sailed along the ice barrier in an effort to find a way through to the south, but, as Novosilsky writes, "there was no passage anywhere" (*Russian Discoveries in the Antarctic*, Moscow, 1951, p. 219).

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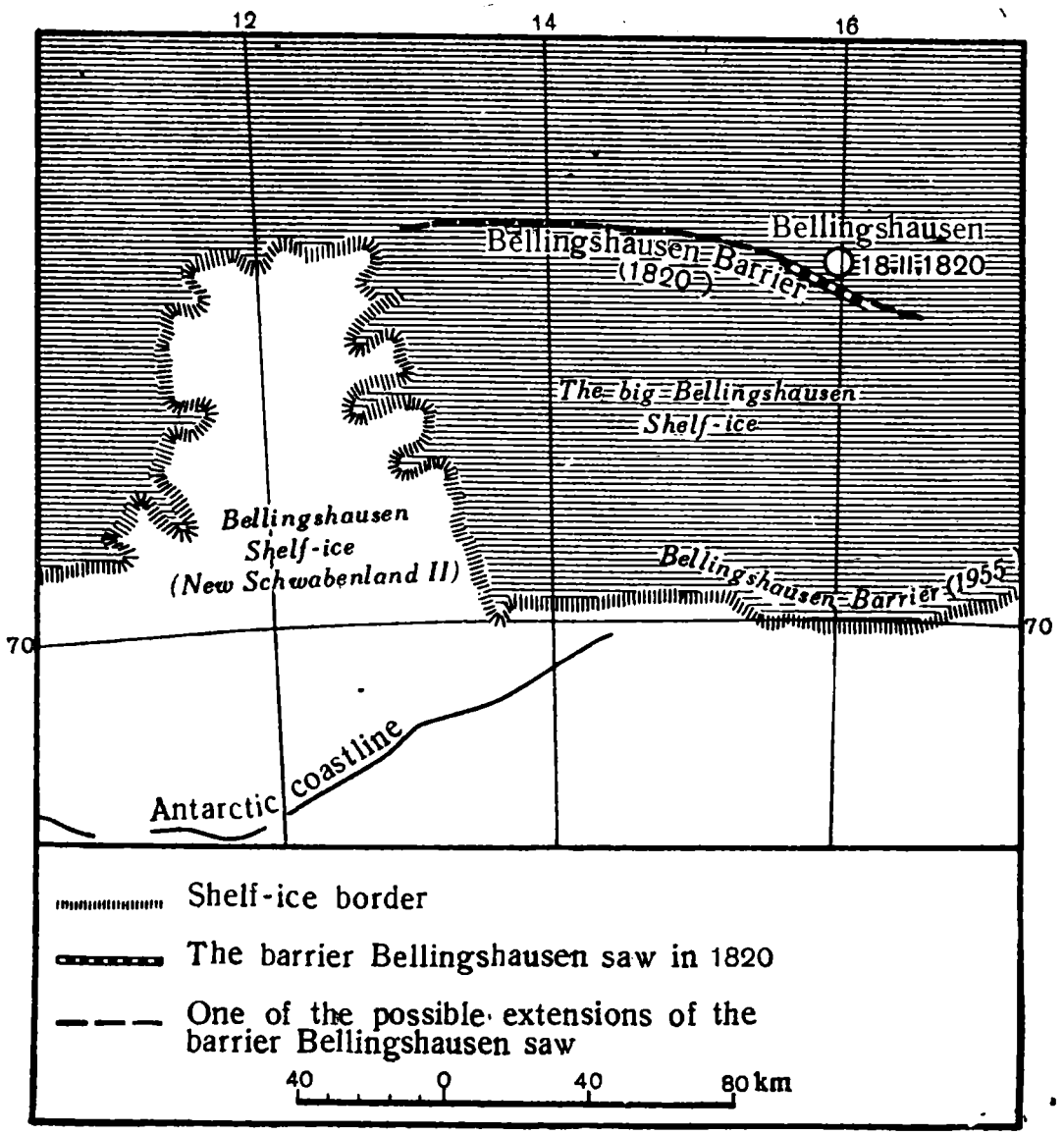
[1] The description of the icebergs was given by Midshipman P. N. Novosilsky of the *Mirny*.

[2] *The Antarctic Pilot* (London, 1948) says Bellingshausen saw and described, but did not recognize as land, part of the Antarctic coast now known as Princess Ragnhild Land.



Bellingshausen's vessels off Princess Astrid Land (after the Antarctic Navigation Chart, 1955)

Judging by the 1955 Navigation Chart, the ice barrier discovered in these parts by Bellingshausen has by now receded 50 miles to the south, that is, to the very shore of the continent. This shelf-ice, which has by now disappeared almost completely, was never plotted on the map or given a name. The papers of the Russian expedition, however, mentioned the location of its northern edge. It is very probable that the New Schwabenland-II Shelf-Ice,

65 miles west of the section of the barrier approached by Bellingshausen, is what remains of the vast barrier discovered by the Russians on February 17, 1820.

As a tribute to Bellingshausen and to denote the recent recession of the Antarctic barrier ice on the maps, it would be right, in my opinion, to rename the New Schwabenland-II Shelf-Ice "Bellingshausen-New Schwabenland-II Shelf Ice," and the big barrier that has disappeared —"Big Bellingshausen Shelf-Ice." The boundary of this shelf-ice—the "Bellingshausen Barrier"—is shown on the 1820 and 1955 maps.

This is how the Russian explorers described the formation of glacier bergs off the Bellingshausen Barrier: "Seeing the ice islands whose surface and edges were similar to the surface and edges of the above-mentioned ice mass before us, we came to the conclusion that these ice giants and all other similar ice formations had broken off the *matery* coast under the impact of their own weight and, driven by the wind, were now floating all over the Antarctic Ocean" (Bellingshausen, *Double Quest in the Antarctic Ocean and Voyage Round the World in 1819-21.* p. 117).

Continuing survey in the high polar latitudes, Bellingshausen and Lazarev discovered Peter I Island on January 21, 1821, and Alexander I Land on January 28. On February 5, the Russian explorers approached the South Shetland Islands, and surveyed and mapped their shores. After that the ships turned northward.

By that time Bransfield had completed his cruise in the *Williams*. In January 1820, he surveyed the South Shetland Islands, but there were dense mists and he mistook some of the lesser islands for capes. On January 30, Bransfield approached the northern extremity of Graham Land and, sailing along its coast, mapped the continental coastline between 60°30′ and 59°48′W. and between 57°24′ and 56°48′. He named it Trinity Land, now known as Trin-

ity Peninsula (E. W. Hunter-Christie, *The Antarctic Problem*, London, 1951, p. 64).

The American sealer Nathaniel Palmer, sailing in the schooner *Hero*, approached the continent in November 1820. On November 15, from the peak of the volcano on Deception Island, he saw land to the south and it might have been either the continental coast or an offshore island. The check-up on Palmer's itinerary, made recently by the American Hydrographic Board with due consideration of magnetic anomalies, and the entries in the *Hero's* log, deciphered by L. Martin, show that Palmer approached the continent off Trinity Island on November 17.[1] As a tribute to the American discoverer, the British Admiralty decided to name the southern shore of the strait between the continent and Trinity Island Palmer's Coast.

In those days the South Shetland Islands were frequently visited by British and American sealing ships—there were 44 of them in the 1820-21 season and 91 in the following. R. Fildes, one of the sealers, wrote that some of these vessels tried to penetrate farther south. In fine weather one could see snow-blanketed mountainous land[2] to the south of Deception Island, he said, adding that Captain McFarlane landed there and found many Leopard and Elephant Seals, but no Fur Seals. Another man to land on this coast, according to Fildes, was Captain Usher. The American sealer Daniel Clark wrote to the editor of the *New Haven Journal* on February 18, 1821, that he had seen land in 66°S., south of the South Shetland Islands.

On December 7, 1821, the American sealers George Powell and Palmer discovered the South Orkney Islands.

In 1822-24, James Weddell, exploring the southern

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[1] Earlier sources gave other dates. The memorial plaque in Palmer's hometown says he discovered the Antarctic coast on January 14, 1821.

[2] Graham Land and off-lying islands.

waters for Fur Seal rookeries, reached 74°15′S. in 34°17′W. in what was later named Weddell Sea.

In February 1831, the sealer John Biscoe, retired Master, R. N., discovered Enderby Land, and in 1832, in the Bellingshausen Sea, he sighted a mountainous coast which he named Graham Land. What he apparently saw, however, was a group of off-shore islands and not the peninsula.

In 1833-34, Captain Kemp discovered Heard Island and Kemp Land.

In 1839, the sealer John Balleny discovered the Balleny Islands and Sabrina Land.

Important data on the Antarctic regions were collected by the Dumont d'Urville (1837-40), Wilkes (1838-40) and Ross (1839-43) expeditions.

In 1841, James Ross discovered the 250-mile-long barrier which was later called after him. In 1898-1900, with the aid of his papers and photography, explorers succeeded in establishing for the first time how much the shelf-ice had receded to the south. Ross brought back with him granite samples from Possession Island off Victoria Land.

Wilkes and Dumont d'Urville carried out important research work, discovering on icebergs deposits of sandstone, granite and other continental-type rocks. Wilkes also observed basalt blocks up to two metres in diameter. Dumont d'Urville returned home with a collection of granite and gneiss rocks, which he had found off the Adélie Land coast. These were the first geological proofs of the existence of the continent.

Moreover, the three expeditions discovered new Antarctic coast: Victoria Land (Ross), Adélie Land (Dumont d'Urville) and Wilkes Land (Wilkes).

After these discoveries there were no Antarctic expeditions until the British *Challenger* expedition of 1872-76. The *Challenger* collected valuable data, adding to man's knowledge of the bottom topography and submarine geology of the Antarctic seas. It was notably established that

in the northern parts of the Antarctic Archaean terrigenous deposits are overlaid by younger diatomaceous oozes. The expedition returned with important oceanographic, biological and geological evidence. The latter was summarized by Sir John Murray, well known for his hypothesis that the Antarctic Continent was not only a conglomeration of ice and land, but also "geologically a continent."[1]

The Norwegian whaling expeditions headed by Carl Larsen (1892-1924) carried out some very interesting survey. He made the first fossil discoveries on Seymour Island off the eastern coast of Graham Land in 1892. These were sediments dating to the latter Tertiary period and included fossil flora of conifers. Larsen also discovered and first surveyed the Larsen Barrier (1893) and found big whale packs in the Ross Sea (1924).

Lars Christensen's Norwegian expedition (1894) was the first to land on the continent[2] at Cape Adare. On that occasion the naturalist Carstens E. Borchgrevink collected samples of granite which proved of inestimable value to the geologists in their arguments on whether Antarctica was a continent or an archipelago.

The first 12-month drift voyage in the Antarctic waters was made by the *Belgica* expedition in 1898-99 when the ship was caught in the pack-ice of the Bellingshausen Sea. The direction of the drift confirmed (and Bellingshausen had observed it back in 1820-21) that off the continent the West Wind Drift gave way to the East Wind Drift.

The British Southern Cross Expedition of 1898-1900, financed by the London publisher George Newnes and headed by Borchgrevink, surveyed the Ross Barrier and established its recession southward.

It was Borchgrevink, too, who first wintered on the continent, spending nine months in Victoria Land.

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[1] Even at the turn of the century many British writers still referred to "Murray's hypothetical Antarctic Continent."

[2] Unless one considers the landings made in Graham Land by McFarlane and Usher.

In 1898-99, the German vessel *Valdivia* surveyed the Antarctic.

The Swedish expedition aboard the *Antarctic*, headed by Prof. Otto Nordenskjöld, surveyed the glaciers and coast of Graham Land in 1901-03.

In these same years a German oceanographic expedition under Erich von Drygalski (aboard the *Gauss*) wintered off the Antarctic coast at 90°E.

Robert Scott's first expedition (1901-04) aboard the *Discovery* surveyed the Ross Barrier, confirmed its recession southward and established the part played by tides in the destruction of shelf-ice. The British explorers wintered on Ross Island and organized a sledge party to 82°17′S., reaching a point 857 kilometres from the Pole.

Dr. W. S. Bruce's expedition aboard the *Scotia* (1902-04) surveyed the ocean, discovered Coats Land and set up a meteorological station on Laurie Island (it now belongs to Argentina).

A French expedition under Dr. Jean Charcot aboard the ship with the witty name of *Pourquoi pas?* ("Why not?"), surveyed the Bellingshausen Sea in 1908-10 and mapped some of its shores.

A British expedition headed by Sir Ernest Shackleton (aboard the *Nimrod*, 1907-09) wintered on Ross Island, made an exploratory sledge trip to the South Pole and surveyed a big stretch of Victoria Land. The expedition was the first to cross the Ross Barrier, discover the South Polar Plateau and traverse it to 88°23′S. (179 kilometres off the Pole). Another party of Shackleton's expedition, headed by T.W.E. David, reached the south magnetic pole. Taking part in this expedition was young Douglas Mawson. The results of Shackleton's expedition are analyzed in more than sixty polar works. Shackleton's second expedition aboard the *Endurance* was ill-fated. The ship drifted in the Weddell Sea for ten months in 1915-16 and was eventually crushed by the ice.

Wilhelm Filchner, who headed the *Deutschland* expedition in 1912, landed on the shelf-ice in the southern part of the Weddell Sea. This shelf-ice is now known as the Lassiter Shelf-Ice, Filchner Barrier and Weddell Barrier.[1] Caught in the ice, the *Deutschland* drifted for nine months, in approximately the same direction as the *Endurance*. The drift of these two vessels revealed the direction of the surface current and wind in the Weddell Sea. Moreover, the German explorers were fortunate to observe from very close distance the breaking off of ice-tongues from the Filchner Shelf-Ice and their formation into icebergs.

Captain Scott's new expedition in the *Terra Nova* carried out important research on the continent when they wintered on Ross Island in 1911 in preparation for their trip to the Pole.

There are more than 100 British articles and books on the results of this expedition and the South Pole trip, and many of them are still being issued by the British Museum in London.

Roald Amundsen's expedition aboard the *Fram* (1910-12) wintered on the Ross Barrier in the Bay of Whales. A five-man sledge party reached the South Pole on December 14, 1911.

A month later, on January 17, 1912, this was also done by Robert Scott's group, but all the five men, including Scott himself, perished on the way back.

In 1911-14, Sir Douglas Mawson's expedition explored the Antarctic waters (aboard the *Aurora*) and the continent, surveying Adélie Land, notably in the region of the magnetic pole. Two parties wintered on Cape Denison and on the Shackleton Shelf-Ice. The expedition, whose findings have been treated of in something like fifty works, discovered King George V Land, Queen Mary

[1] In the U.S.S.R. World Atlas of 1954 and the Navigation Chart of 1955, the western part of the barrier is given as Lassiter Shelf-Ice and the eastern as Filchner Barrier.

Robert Falcon Scott

Land and the Ninnis and Mertz glaciers and Shackleton Shelf-Ice.

The *Aurora*, which carried the Mackintosh Expedition of 1915-16, drifted in the Ross Sea for nine months. The drift showed that there was an eastward deflection of currents along the continent's coast in the Ross Sea, similar to that reported by the *Belgica*, *Endurance* and *Deutschland* from the Bellingshausen and Weddell seas.

Systematic British expeditions to the Antarctic were begun in 1925 by the Discovery Committee, which was set up by the British Government in 1923 for the purpose of enhancing the Empire's economic and political positions at the Antarctic outposts.

The Committee's main tasks were to compile maps of the Falkland Islands Dependencies and service the British whaling industry. The latter was entrusted with the task of investigating the species of whales, their food, grounds, the sea currents, bottom topography, the adjacent lands, etc. In 1925, the Committee set up a marine biology laboratory under N. A. Mackintosh. The Committee's ships, the *Discovery* (and after 1929 the new *Discovery II*) and the *William Scoresby* carried out fifteen expeditions prior to 1939 (after 1929 they were organized every year). The *William Scoresby* took care of whale-marking, while the *Discovery* (and after her the *Discovery II*) carried on with oceanographic and biological survey. G. Deacon used the materials of the *Discovery II* expeditions in his *Hydrology of the Southern Ocean* (1937),

which is still considered one of the best manuals on Antarctic Ocean hydrology.

Excellent results were obtained by the British-Australian-New Zealand Antarctic Research Expedition of 1929-31 under Mawson (aboard the *Discovery*). One of the first expeditions to resort to air reconnaissance, it discovered MacRobertson Land, Banzare Coast and Princess Elizabeth Land.

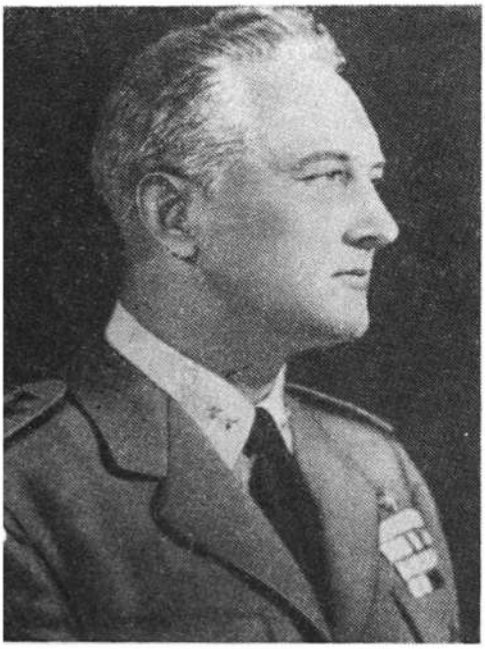
Roald Amundsen

A British expedition under John Rymill, doing research work in Graham Land, discovered that it was not an archipelago as previously assumed, but a peninsula. It was Rymill, too, who discovered the ice-bound strait between Alexander I Land and the continent.

The outbreak of hostilities in the South Atlantic in 1939 compelled the Discovery Committee to suspend operations.

The Discovery Committee's work was taken over by the Falkland Islands Dependencies Survey, which came into being in 1943 and which is now engaged chiefly in coastal survey in Graham Land and adjacent islands, as well as by the National Institute of Oceanography, which was set up in 1949. The latter has taken over the *Discovery II* and the *William Scoresby.*

After World War I there were three German expeditions to the Antarctic, the chief being the one on the *Meteor* (1925-27), which surveyed among other things the South Sandwich Trench. The German *Schwabenland* Expedition



Admiral Richard Byrd

carried out air survey of the Antarctic coast between 11°W. and 20°E., taking aerial photos over an area of 350,000 square kilometres.

In 1930-31, Norwegian whalers discovered Lars Christensen Coast and other coastal territories.

In 1939, an expedition was sent by France in the *Bougainville* to do research work in the Indian Ocean sector.

Towards the end of the 1920's aircraft began to play an important part in Antarctic exploration. Planes were used by British, United States, Australian and Norwegian expeditions.

The first flight over the Southern Continent was made on November 16, 1928, by Sir Hubert Wilkins, although sixteen years earlier Scott's expedition had used a balloon over what is today known as the Bay of Whales and what was then an inlet which Scott called Balloon Bight. One of the pioneers in air reconnaissance was Sir Douglas Mawson.

Particularly important air survey in the Antarctic was carried out by four explorers: Wilkins, who made flights over Graham Land in 1928-30; Lincoln Ellsworth, who was the first to fly over the continent from Graham Land to the Ross Sea (1935) and who made flights over Ingrid Christensen Land (1938-39); Admiral Byrd, who flew to the South Pole in 1929 and 1947, spent three winters in the Ross Sea from which he reconnoitred the continent from the air (1928-30, 1933-35 and 1939-41) and headed an American naval task force in 1946-47; and Finne Ronne,

who directed a private American expedition which carried out extensive air survey in the region of Graham Land and off the Weddell Sea coast in 1946-48.

Byrd's 1946-47 expedition, with 4,400 men engaged, was the biggest ever undertaken in the Antarctic. It used powerful weasels, icebreakers and submarines. Air photos were taken of a territory almost 1,000,000 square kilometres in size and over 9,000 kilometres of the coastline were charted. It was also the first to investigate the character of the surface below the ice-cap with the aid of an airborne magnetometer, a thereto secret U. S. Army instrument, which was suspended from the plane on a 30-metre-long cable. Altogether four flights were made with this instrument. One interesting conclusion was that the south magnetic pole had deviated 270 kilometres north westward.

The Ronne expedition in November 1947 discovered a vast shelf-ice in the southern part of the Weddell Sea (it was on the easternmost extremity of this shelf-ice that the Filchner expedition landed in 1912) and called it Lassiter Shelf-Ice after one of the flyers of the expedition. Ronne also discovered land south of the shelf-ice and named it Edith Ronne Land.

American explorers surveyed the region between Wilkes Land and Marguerite Bay (Graham Land) in the icebreakers *Edisto* and *Burton Island* in 1947-48, and cabled weather charts over a distance of 18,000 kilometres.

In 1954, the *Atka,* a U.S. Navy ice-breaker sent to the Antarctic on a reconnaissance cruise in preparation for the International Geophysical Year, collected data on geomagnetism and cosmic rays. Summarized and complemented since then, this data has permitted American scientists to displace the point of the magnetic pole 600 miles to the west of the location computed in 1945 (lat. 78°S., long. 109°E.).

In 1948-49, the British organized a big sledge expedition in Graham Land and surveyed its western coastline all the way to 71°35′S. The explorers covered over 1,700

kilometres and charted 430 kilometres of the coast. At 70°46′ they discovered mountains free of snow, and thawing streams and lakes.

A big joint Norwegian-British-Swedish expedition, headed by Dr. H. W. Ahlmann, Dr. H. U. Sverdrup and J. M. Wordie, wintered in Queen Maud Land in 1949-52, and surveyed the locality, the thickness of the ice-sheet and its structure (drilling shafts to a depth of 100 metres) within the radius of 600-700 kilometres.

In 1948, the French organized an Antarctic expedition in the ship *Commandant J. B. Charcot* and in the following year the vessel *La Perouse* gathered hydrographical data off Adélie Land.

In the period 1950-53 the French established a base named Port Martin on Cap de Margerie, in lat. 66°49′S., long. 141°24′E., from which a winter programme was operated. The explorers collected a complete set of geological samples and brought back data on ionospheric soundings, seismology, biology, hydrography and meteorology. The Port Martin base was destroyed by fire in 1952, but the winter programme was continued until the following year on Pointe Géologie.

A. Scholes writes in *Seventh Continent* (London, 1953) that the French expedition covered 2,700 kilometres and mapped the greater part of the Adélie Land coastline.

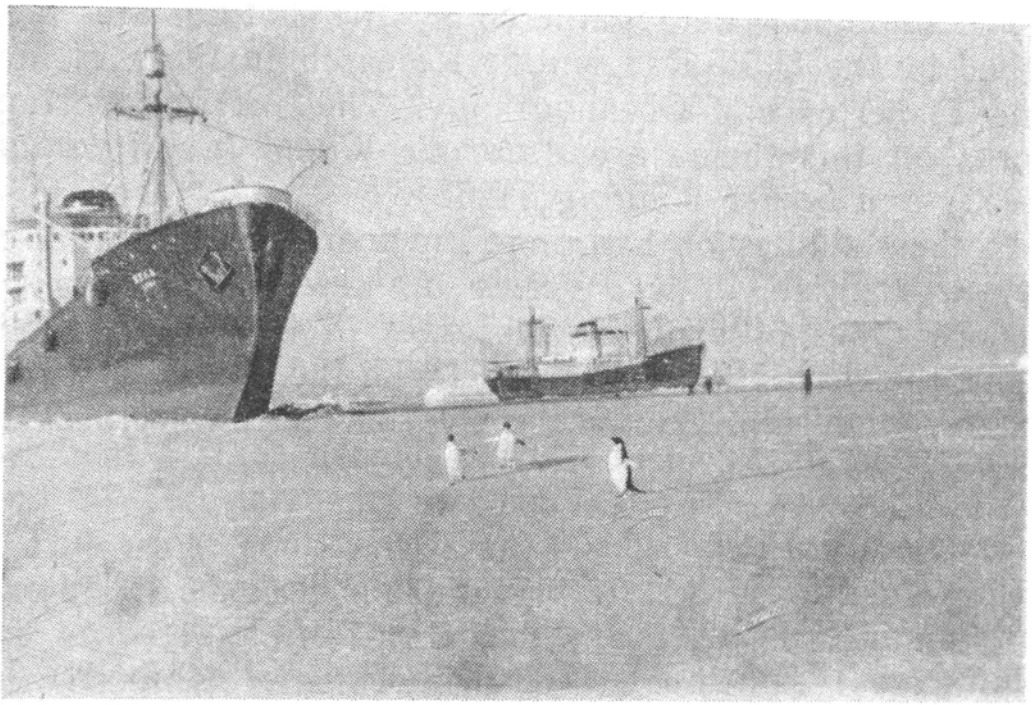
In 1949-53, several Argentine and Chilean bases were set up in the Falkland sector, over which bitter political rivalry is going on between these two countries and Britain.

In 1948, Chile sent a military expedition to the Antarctic aboard the *Presidente Pinto*; in the following year she organized another military base and built a landing strip on Greenwich Island; in 1952, she began building a 1,200-metre-long landing strip on Deception Island.

In 1951, Argentina established bases in Marguerite Bay and Hope Bay and on Dundee Island. A new Argentine base was started in 1953 on Livingston Island.

A permanent Australian research station named after Sir Douglas Mawson was set up in 1954 on the coast of the Southern Continent (62°53′E., 67°36′S.).

Soviet scientists have been carrying on research in the Atlantic sector of the Antarctic since 1946 aboard a spe-



The *Ob* and *Lena* off the Antarctic shore, 1956

cially equipped ship with the *Slava* whaling flotilla, collecting data on hydrology, meteorology, geology and glaciology, as well as gathering plankton, flora and fauna samples, and conducting whale investigations (accounts on habits and marking). Investigation of the whales caught and determination of their age, size, weight and anatomy are carried out aboard the factory ship *Slava.*

The results of the flotilla's investigations are summarized in annual reports, while the data on hydrology and meteorology are published by the State Oceanographic Institute (so far it has put out unabridged hydrometeorological reports for 1947-48, 1948-49, 1949-50 and 1951-

52). Moreover, more than ten articles and books have been written on the basis of the hydrological and meteorological materials collected by the flotilla, the most important being the two-volume *Antarctica* (Gidrometeoizdat, 1956-57) by G. M. Tauber and Y. V. Makerov, who have taken part in the *Slava* expedition.

The biological data gathered by the flotilla are published by the U.S.S.R Scientific Research Institute of Marine Fisheries and Oceanography. The most important works on this theme are *Antarctic Whale Investigations* (1953) and *Soviet Whaling* (1955).

In their studies on hydrology, meteorology and biology Soviet scientists draw a series of new conclusions on various types of synoptic processes in the Antarctic regions, the circulation and character of the Southern Ocean waters, the reproductive cycle of certain types of whales, etc.

GENERAL FEATURES OF ANTARCTIC NATURE

ANTARCTIC LANDS

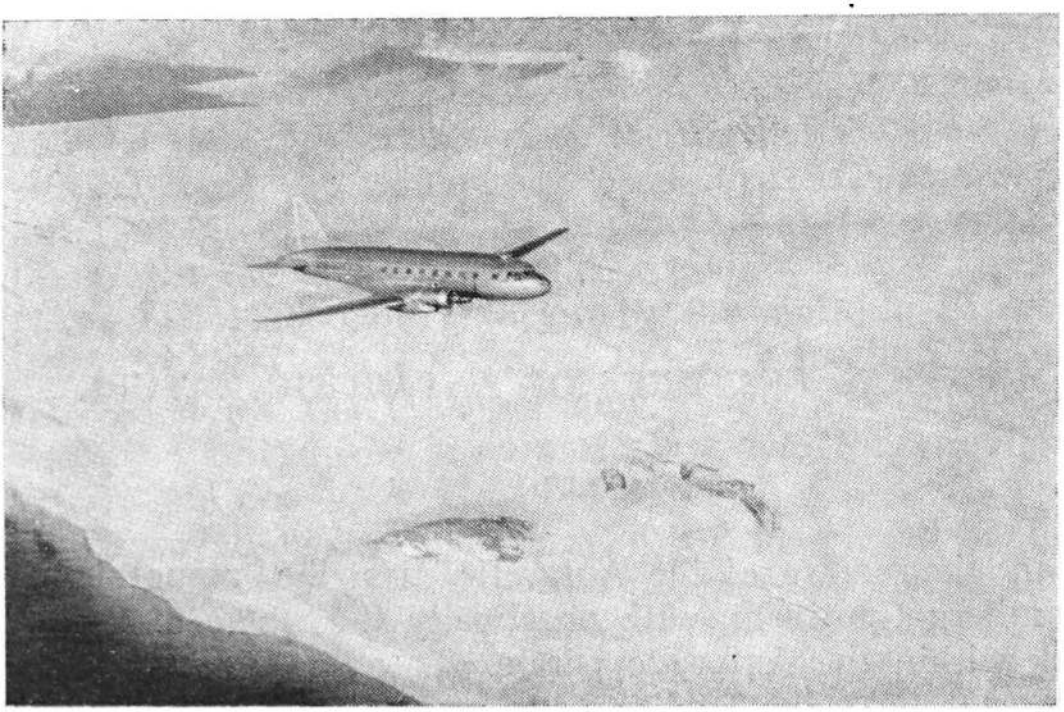
In the centre of the Antarctic lies the mountainous Southern Continent, with practically the whole of it falling within the Antarctic Circle.

In lat. 65°S. the land and the continental ice occupy five per cent of the surface, in 70°—50 per cent, between 70° and 80°—95 per cent, and south of 80°—100 per cent.

This great continent is 14,070,000 square kilometres in extent, of which 930,000 are covered by continental shelf-ice protruding into the ocean and 40,000 by the shelf-ice of Alexander I Land which is welded into the common mass on the continent. In size the Southern Continent is bigger than Europe (11,600,000 square kilometres) and Australia (8,900,000 square kilometres) and extends over about one-fourth of the entire Antarctic expanse.

Antarctica is obscured by a thick mantle of ice which somewhat smoothes out the elevations and depressions of the land surface and straightens out the coastline. The average thickness of the ice-cover is not yet known but in the past seven years or so the figure has risen from 550 metres to 2,000 and even 3,000.

The three main curves in the continent's coastline are in the Atlantic and Pacific sectors. It is Graham Land, lying between 55° and 70°W. and stretching northward via Trinity Peninsula to 63°7′S., and the Weddell and Ross seas, whose bays cut into the continent up to 78°S., where



The IL-12 plane over the Davis Sea coast (photo by the Soviet Antarctic expedition)

they are held back by continental ice barriers. Scientists divide the continent into two uneven parts—West and East Antarctica, drawing the boundary along the southern shores of these two seas. The area of West Antarctica (without the shelf-ice) is 2,690,000 square kilometres and of East Antarctica—10,410,000 square kilometres, or three-fourths of the entire continent. The shores of East Antarctica are very little dissected and border almost evenly on the Antarctic Circle in the Indian Ocean.

The coastline is probably made even by the ice-cover. Seismological soundings have shown that there are fjords and rocky archipelagoes under the ice.

East Antarctica is a vast ice-encumbered plateau.

The central part of the continent—the South Polar Plateau—is on the average 2,700 metres above sea-level in some places and up to 3,500 in others. The geometric centre of the continent is 4,200 metres above sea-level.

In the Atlantic and Pacific sectors East Antarctica is

fringed by rocky ranges, crescentic in shape, with the outer arc turned towards West Antarctica.

At the Atlantic "end" of the crescent lie the Queen Maud Land ranges. This vast mountainous region, with summits rising to 4,200-4,300 metres, is 200 kilometres inland between 10°E. and 25°W. The mountains farther east slope away. In Enderby Land and Kemp Land there are some peaks 1,900 and 2,200 metres high, but elsewhere they are much lower.

The Pacific "end" is in the north of Victoria Land. Stretching south and southeast are the Britannia Range with summits rising to 3,228 metres (Mt. McClintock) and the Queen Alexandra Range with Mt. Markham (4,572 metres) and Mt. Kirkpatrick (4,450 metres). Off the southern and southeastern inner edge of the ice barrier lie the Commonwealth Range with summits rising to 4,054 metres, the Crown Prince Olav and Fisher mountains (4,010 metres), Horlick Mountains (3,000 metres) and the Queen Maud Range with peaks of up to 4,600 metres.

It is not known whether the Pacific "end" of the crescent is connected with the Atlantic mountain barrier which runs parallel to the zone dividing West and East Antarctica. U.S. air reconnaissance in 1955 revealed a range with summits rising 1,500-1,800 metres in long. 35°E., lat. 80°S., and it is possible that this range is part of such a link. Early in 1956, the British expedition under Dr. V. E. Fuchs carried out air reconnaissance 135 miles south of the Shackleton base (77°57′16″) and discovered the Theron Mountains, rising 1,000 metres above the ice plateau and 1,250 metres above sea-level. In January 1957, the expedition made an air survey of another range—the Tottan Mountains—in 15°E. and 78°S., with peaks of up to 2,760 metres.

Thanks to unusual optical atmospheric conditions, the Tottan Mountains were first seen in October 1956 from the British base in Halley Bay 230 miles away.

The mountains of the above-mentioned crescentic shape are of "horst" type. Many summits in both Victoria Land and Queen Maud Land are crowned with Beacon sandstone layers. According to A. I. Shalimov, the horst crescent was formed by Tertiary tectonic movements, possibly at the site of the more ancient belt of caledonites.

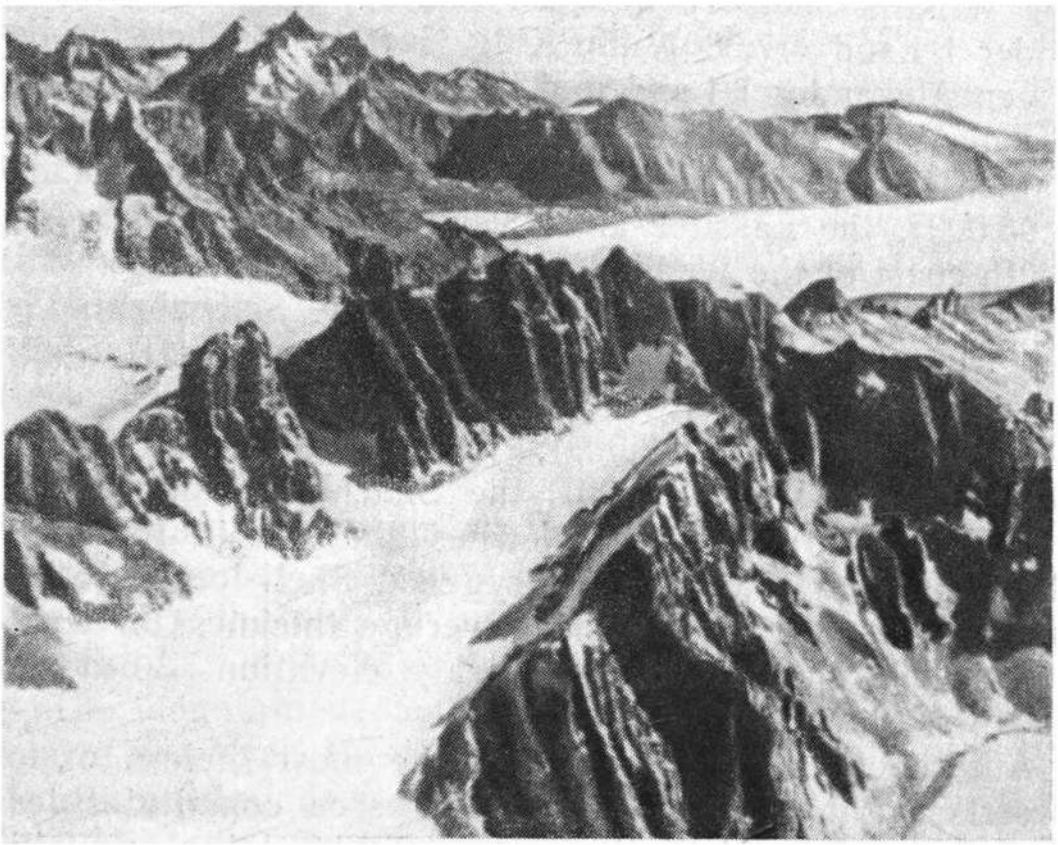
Nothing is as yet known of the rock basement of the central, ice-capped region of East Antarctica. Research done by a French expedition in Greenland in 1948-51 showed that the rock floor under the ice was basin-shaped, the depression being at the same level with the sea. The rock floor of East Antarctica is now believed to be the same.

Physically, West Antarctica is also divided into an ice plateau and mountainous region. The mountains predominate. The young folded ranges--the "Antarctandes"—stretch from one end of Graham Land to another (with summits rising to 3,983 metres), where they split in two —the Wilkins Mountains, receding to the little known Edith Ronne Land, and Sentinel Mountains (summits up to 3,810 metres), extending southwest to lat. 78°S., long. 90°E. Almost parallel with this range, though north of it and on a different longitude, are the Executive Committee Mountains (peaks of up to 3,658 metres), while south of it is an unknown height of 100 metres. These mountains start in 110°W., 76°S. Farther west, are Hal Flood Mountains (3,048 metres), running parallel to Hobbs Coast, and, finally, on the Ross Sea coast, the Edsel Ford Range (summits rising to 1,090 metres).

The Antarctic Andes are formed by Alpine folds, in places (Graham Land) marred by geosynclinal sediments.

The above-mentioned ranges, and the smaller ones, form a mountainous country of parallel ridges with ice plains lying in-between.

South of this mountainous country is the ice plateau rising in some places to 2,000 metres and then sloping down in two directions: to the Ross Sea and to the zone



Queen Maud Mountains (German Antarctic expedition, 1938-39)

dividing West Antarctica and East Antarctica, a depression 500 metres wide.

There are active volcanoes both in West Antarctica and East Antarctica. On the off-lying Ross Island is the 4,023 metre-high Mt. Erebus. In 1893, sailing off the east coast of Trinity Peninsula, Captain Larsen observed eruptions on Lindenberg and Robertson islands.

From the air, the greater part of Antarctica looks like a flat and homogeneous ice- and snow-capped surface. The ice mantle covers more than 96 per cent of the continent's territory and protrudes into the sea in the shape of shelf-ice and ice-tongues. The biggest is the Ross Barrier (488,000 square kilometres). Other important barriers east of it are: the Sulzberger Shelf-Ice in 150°W. (13,000

square kilometres), the Getz Shelf-Ice in 130°W. (20,000), the Wilkins Shelf-Ice between Charcot Island and Alexander I Land (17,000), the King George VI Shelf-Ice between Alexander I Land and the continent (28,000), the Wordie Shelf-Ice in Marguerite Bay in 65°W. (400), the Larsen Ice Barrier along the east coast of Graham Land (103,000), the Lassiter and Filchner Shelf-Ice along the south coast of the Weddell Sea (165,000), Stancomb Wills Promontory in 25°W. (2,900), the New Schwabenland-I Shelf-Ice in 0° (1,900), the New Schwabenland-II Shelf-Ice in 15°E. (16,000), the Emory (Ingrid Christensen) Shelf-Ice in 72°W. (13,000), the Drygalski (or West) Shelf-Ice in 85°W. (29,000), the Shackleton Shelf-Ice in 100°W. (39,000), the Lady Newnes Shelf-Ice in 166°W. in the Ross Sea (5,000), the Drygalski Shelf-Ice in 164°W. in the Ross Sea (3,000). The average thickness of ice is around 200 metres and the average elevation—30 metres above sea-level.

Antarctica is the biggest and the most lifeless of ice deserts on the Earth. The ice-free area constitutes less than four per cent of its surface, with plains and hills occupying about 2,000 square kilometres and steep mountains—the rest. Even in the summer the temperature in the central regions rarely rises above —30°C.

There are no bears, foxes or any other animals one finds in the north polar regions. The biggest land inhabitant is the wingless mosquito 15 millimetres long. In the coastal "oases," that is, in places free of ice, one occasionally comes across lichens and mosses.

Antarctica, separated from the other continents by a vast ocean belt, is approximately 800 kilometres from South America, 3,400 kilometres from Africa and 2,900 kilometres from Australia. The Antarctic water basin is 37,800,000 square kilometres in area. The average depth is 4,000 metres.

The islands are few and far apart, and their total area, excluding Alexander I Land, is about 38,000 square kilo-

metres. Most of them lie off the Antarctic coastline and if the area of these off-shore islands were deducted, the area of those farther out at sea would hardly exceed 10,000 square kilometres. The biggest of the latter are South Georgia (4,000) and Kerguelen Island (3,000).

Though separated by vast distances, the Antarctic islands have very many common features: most of them are of volcanic origin, mountainous and rise high above sea-level. They are obscured by thick mists and darkness, and covered with eternal snow and glaciers debouching into the ocean. The high, precipitous shores, numerous submarine rocks and mighty breakers make them almost inaccessible.

The scant vegetation on the little patches free of snow in the summer is limited chiefly to lichens and mosses. Birds are the only living things these rigorous islands abound in.

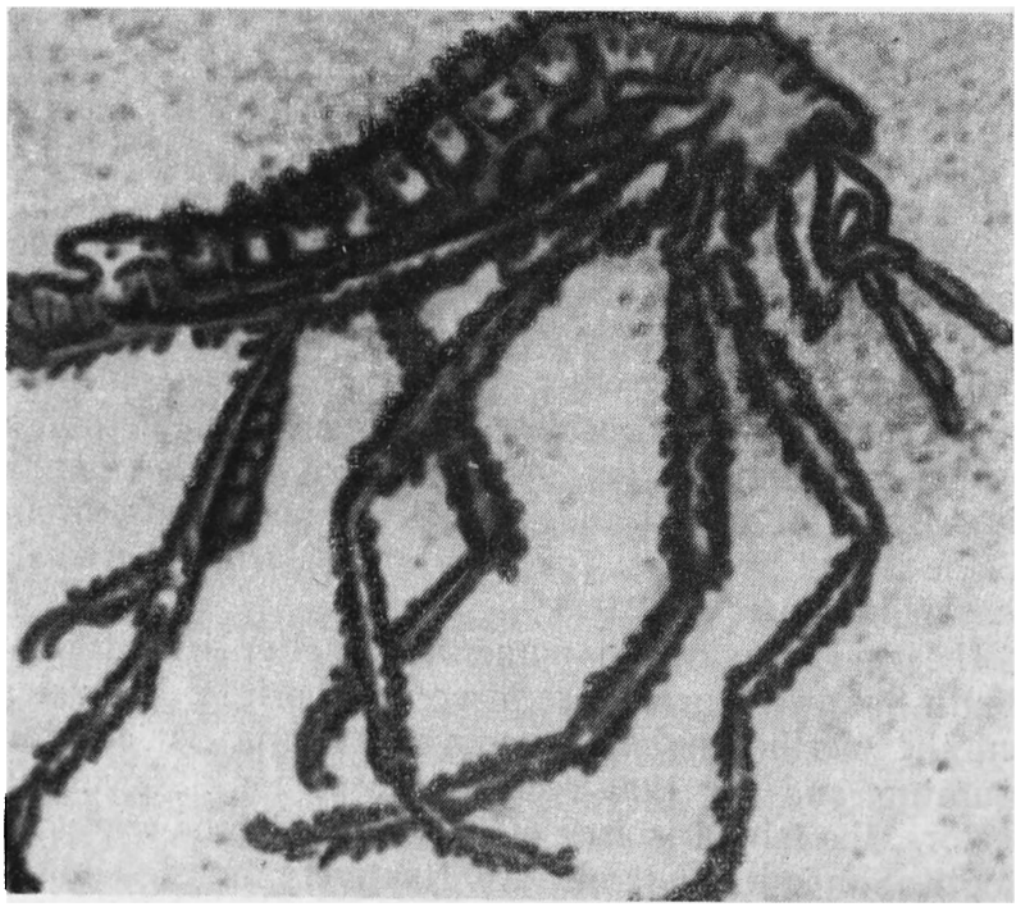
The mountainous South Georgia Island is 2,840 metres above sea-level. Its coast is all dissected, with bays and fjords cutting deep inland. The glaciers descending the valleys form numerous icebergs which present a great menace to ships approaching the island. In the northeast there are patches of grass that serves as feed for the sheep and reindeer brought there, the latter long since turned wild. Compared with other Antarctic islands, South Georgia is rich in fauna. Besides seals, Sea Elephants and Sea Leopards, penguins, sea swallows and petrels, there are three types of land birds, as well as many rats, brought to the island by ships. The population during the whaling season increases to 2,000.

The seven main and numerous smaller islands of the South Sandwich group are of volcanic origin. The volcano on the northernmost Zavodovski Island is constantly erupting and for that reason, except for a few coastal sectors, the island is free of snow even in the winter. The South Sandwich Islands are relatively inaccessible and almost completely unexplored. Mist, poor visibility and

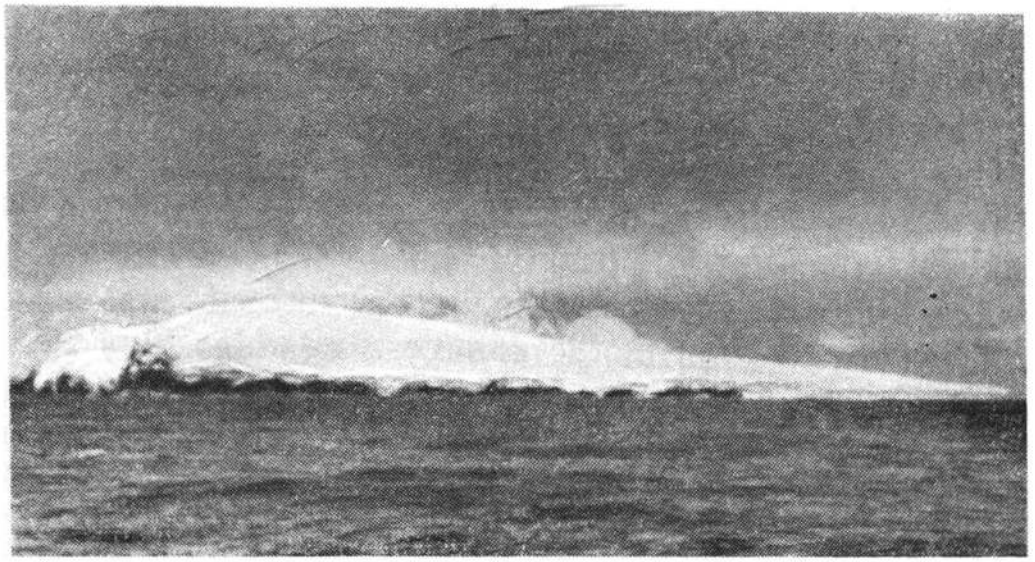
snow are common features. In summer there are patches of grass in the plains, especially where the penguins nest. There are many different birds. Of the seals there are Sea Leopards and Weddell Seals.

The South Orkney Islands are covered with ice and snow right to their steep capes and cliffs. There is no vegetation.

Except for two islands, the South Shetlands are of volcanic origin, mountainous (with peaks rising to 2,012 metres) and covered with eternal snow and ice. Only in summer, in January, do the snow and ice melt in some parts along the coast and then low grass grows in patches here and there. The few beaches are the only places where landings are possible. Once there were rich seal rookeries



Wingless mosquito (J. Machowski, 1953)



The western part of Bouvet Island—54°26′S., 3°24′—in summer
(photo by the author)

on the islands. Small deposits of high-quality coal have been discovered there.

The volcanic Bouvet Island was formed by black lavas and is covered with an ice dome. A hanging glacier descends the eastern slope into the sea. The island's shores are rocky and steep and only in the north are there any patches of moss and lichen. Its fauna is limited to birds, mainly petrels. Sometimes small numbers of seals gather on its shores.

Kerguelen Island, lying on the Antarctic boundary in the Indian Ocean sector, is one of the most interesting of the south polar islands. It is surrounded by 130 rocky islets. The climate is cold, damp and windy. Snow falls throughout the year. In the interior there is a rocky plateau with lakes and many waterfalls, some of them nearly 600 metres high. Glaciers move down the mountains (their summits rise to 1,865 metres) to the ocean.

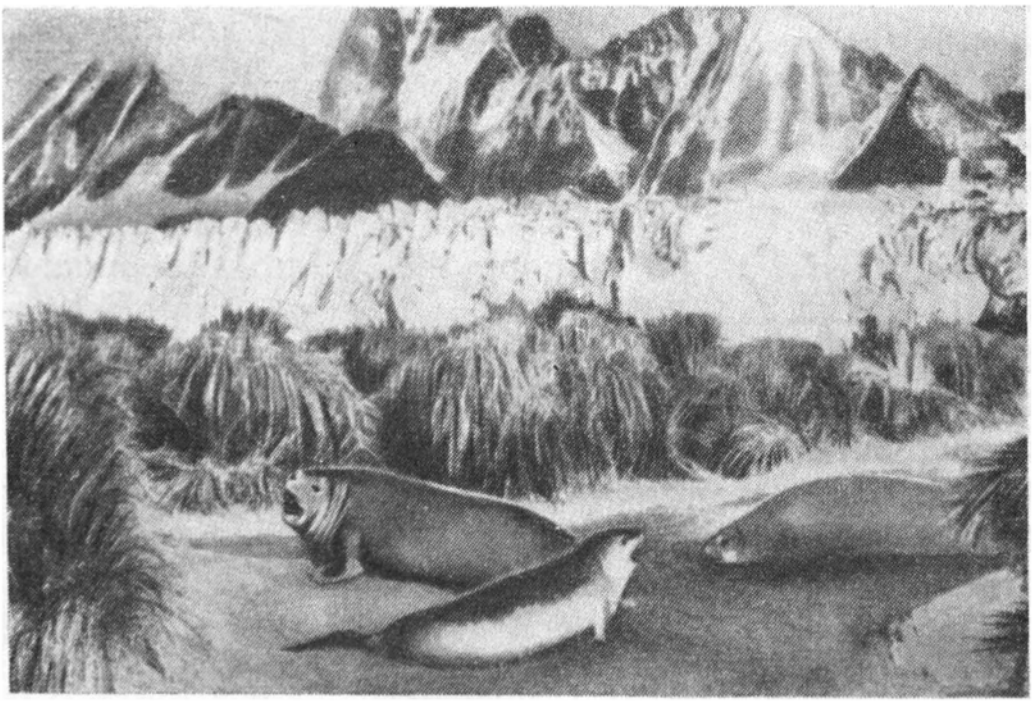
The flora includes several types of moss and grass, among them the Kerguelen cabbage which is famous for its antiscorbutic properties. The fauna is quite rich and, apart from penguins and huge numbers of other birds,

there are many rabbits, rats and mice brought there by man. The island has been turned into a preserve and hunting is prohibited.

The islands discovered by the Russians in 1821 are difficult of access and present a picture of desolation. Peter I Island, lying 1,220 metres above sea-level, is always blanketed with snow and the ice around it makes approach difficult even in the summer.

Alexander I Land, the biggest island in the Antarctic region, is covered with a thick mantle of continental ice that spreads on to it across the narrow King George VI Sound.

One hundred miles north of the Antarctic Convergence, on the border of the Indian and Pacific oceans, lies Macquarie Island (54°S., 159°E.). It is practically on the same latitude with Bouvet and South Georgia islands and 5° south of Kerguelen Island, but its fauna and flora are entirely different. An excellent description of the island is



Elephant Seals on South Georgia (A. Saunders, 1950)

given in Bellingshausen's report on the round-the-world cruise of the sloops *Vostok* and *Mirny*:

"We expected Macquarie Island to be covered with eternal snow and ice like South Georgia, since both are located in the same hemisphere and on the same latitude, and we were greatly surprised to find luxuriant vegetation everywhere except on the cliffs.... The island abounds in ... wild cabbage.... Of the quadrupeds on Macquarie Island there are wild dogs and cats, originally brought there by the Europeans, which always hide in the dense grass on the elevations." There were many types of sea birds and also little parrots.

The dissimilarity between Macquarie Island and other Antarctic islands lying on the same latitude is graphic evidence of the major differences in the climatic conditions obtaining north and south of the Antarctic Convergence, which we regard as the boundary of the south polar regions.

SOUTHERN OCEAN MORPHOLOGY

Very little is known as yet of the morphology and geology of the Antarctic Ocean, islands and continent. Geologists say they have explored less than half of Antarctica's coastline, while oceanologists admit that there are no two charts of the Antarctic latitudes which agree on the structure of the ocean bed.

The picture of sea-bottom topography is quite unique.

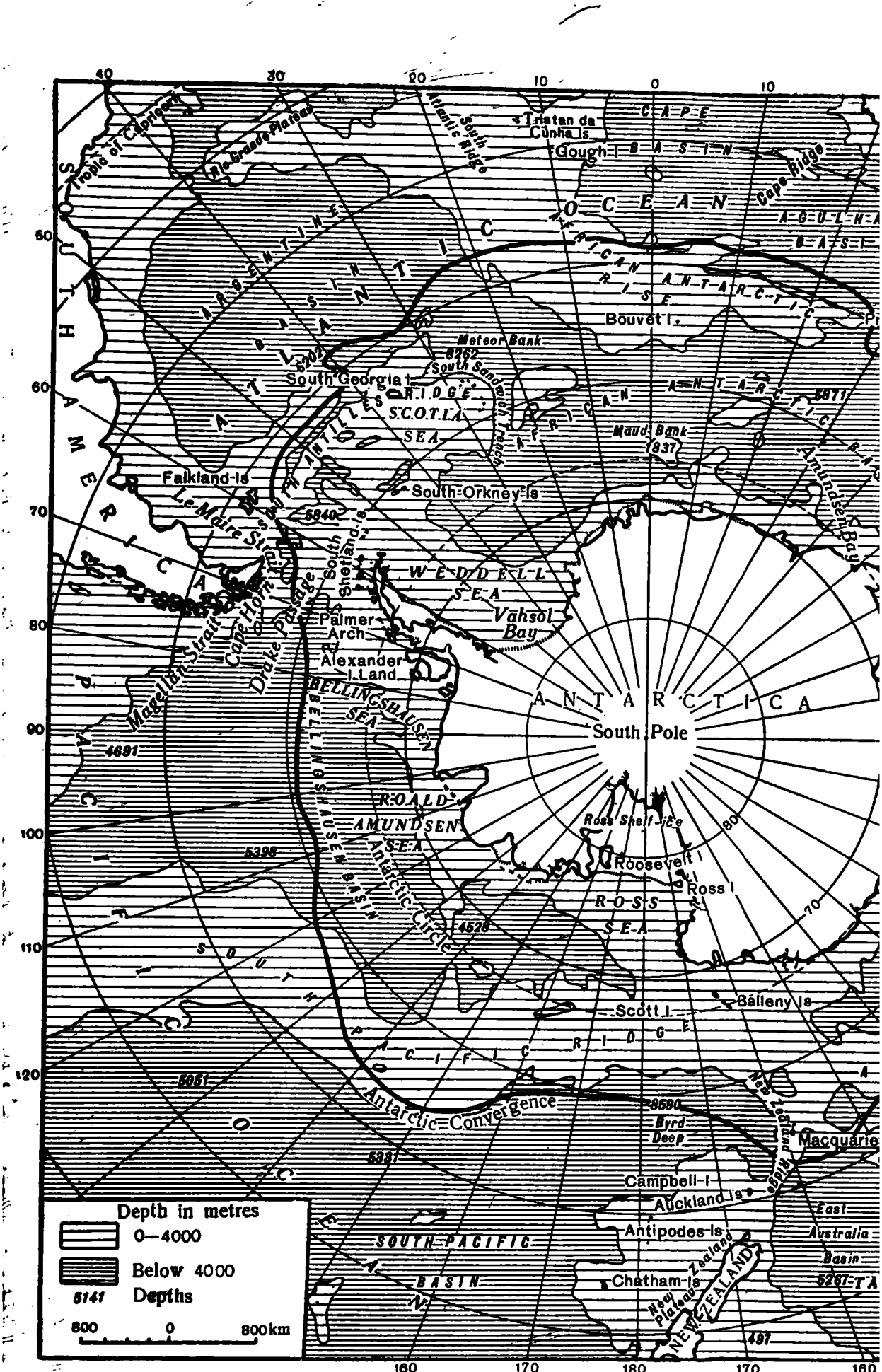
The Southern Continent is surrounded almost completely in lat. 60°S. by three main basins which form the Antarctic Basin: the African-Antarctic Basin (the Atlantic-Indian Antarctic Basin) with depths in excess of 5,000 metres, the Australian-Antarctic Basin (about 4,500 metres deep) and the Bellingshausen Basin (the Pacific-Antarctic Basin) with depths increasing from 3,500 metres off New Zealand to 5,000 metres off South America. From the north these basins are belted by a chain of submarine ridges stretching

in the Atlantic and Indian sectors along the 55th Parallel. In the Pacific sector this chain is continued by the South Pacific Rise (East Pacific Rise) which, however, does not lie on a parallel but swings from WSW to ENE from the New Zealand Rise to Easter Island. The Antarctic Ocean basins are separated by three ridges extending obliquely "like spokes from the hub of a broken cart wheel," to quote Charles A. Fleming (*The Antarctic Today*, p. 103).

One of them—the New Zealand Rise—separates the Australian-Antarctic Basin from the Bellingshausen Basin and stretches from Victoria Land to New Zealand. It is from this rise that spring the Balleny Island and Macquarie Island, the latter a huge volcanic structure more than 500 metres above the sea-bottom but very little above the ocean surface. Macquarie is the third biggest volcano after Terror and Erebus. Plant remains found there show that there probably was some connection in this region between New Zealand and Victoria Land in the Tertiary period. Only in one place within the boundaries of the Antarctic, in 59°S., does the depth of the rise exceed 3,000 metres (3,892).

The second ridge—the South Antilles—connects the Andes in South America with Graham Land and separates the Bellingshausen Basin from the African-Antarctic Basin. The peaks of this ridge form the South Antilles Arc (Scotia Arc), which extends to South Georgia, South Sandwich, South Orkney and South Shetland islands. Many of them are volcanic islands and some of the volcanoes are still active, and that, according to Bourcart, is due to the compression of this region. In the none-too-remote past the Antilles Arc was probably the site of a continental bridge between America and Antarctica. At present the depths between some of its islands exceed 3,000 metres.

The third meridional ridge—the Kerguelen-Gaussberg Ridge—is approximately in the centre of the Indian Ocean sector and from it rise Heard and Kerguelen islands. In



Sea-bottom topography of Antarctica

ome places in the southern part, opposite the Davis Sea, he ridge lies in depths of 3,000 metres and more.

The belt of the submarine ridges surrounding Antarcti- a stretches from the South Antilles Arc to the Hobbs Coast meridian (between the Ross and Roald Amundsen eas) approximately along the latitude of the Antarctic Convergence. Farther down towards South America it urns northward. The African-Antarctic Rise (Indian Cross Ridge) of this belt is separated from the South Antilles Arc y an uneven meridional passage from the Antarctic Basin o the Atlantic, with depths slightly in excess of 4,000 me- res. The African-Antarctic Rise lies in depths of approxi- nately 3,000 metres. It the centre is Bouvet Island, formed f Tertiary volcanics.

South of Africa, the Antarctic Basin is connected by a narrow passage (depth up to 4,000 metres) with the Agul- as Basin, while the latter is linked with the Cape Basin n the Atlantic by depths of approximately 4,500 metres nd with the Madagascar Basin in the Indian Ocean by epths of about 4,000 metres. Then comes the Crozet Pla- eau separated from the Kerguelen-Gaussberg Ridge is- ands by a northward passage with depths of 4,500 metres. This is followed to the New Zealand Rise by the Austral- an-Antarctic Rise (Central Indian Rise) which lies in epths of about 3,500 metres. The South Pacific Rise (East Pacific Rise) lies in depths of approximately 3,000 metres nd follows more or less Antarctica's boundaries to 35° W. In the high latitudes its edges stretch eastward o 120°. West of America the Antarctic Basin does not en- ounter any barriers in the north and links freely with the Pacific.

In the forties the deepest known concave in the Ant- rctic was the South Sandwich Trench (8,262 metres). To- ay it is the Byrd Deep (greatest depth 8,590 metres), dis- overed by echo-sounding (*The Antarctic Today*, p. 107).

Good knowledge of bottom topography and hydrology is ecessary for analyzing the geological connections and

structure of the Antarctic regions, studying their biological phenomena and, finally, understanding the pattern followed by the Antarctic water masses as they flow to low latitudes, as well as the oceanological structure of the Antarctic waters and their vertical movements at the bottom and on the surface.

The Antarctic Convergence is the most important natural boundary of Antarctica. G. Deacon proved in 1937 that its position was determined by the flow of the bottom water and, therefore, by bottom topography.

The Antarctic is the zone where the bottom waters of the oceans are formed, but so far there is no unanimous opinion regarding the centres of their formation and circulation, for scientists tend to assess the influence exerted by bottom topography in different ways.

The study of the Southern Ocean could do much to explain the submarine canyons, for the coastal slopes of the south polar continent had long been different from those of the other continents. Until recently no submarine canyons had been discovered off the Antarctic coast and that might have been due to inadequately detailed soundings. Sailing along the continental slope north of the d'Urville Sea in 1956, the *Ob* crossed a 400-metre V-shaped notch located at the depth of 2,500 metres.

Some relief features very much like submarine canyons had been earlier discovered off certain islands, South Georgia among them, but the opinions voiced on these are quite contradictory.

A geographical peculiarity of the Antarctic is the abnormally deep shelves, and that was especially noted by the *Belgica* expedition (1897-99). While the shelves of the other continents slope between 100 and 200 metres, the Antarctic shelves, according to various authors, have edges in 400 metres and in 500 to 900 metres on the outer boundary of the continent (R. W. Fairbridge, 1952). It is assumed that this is due to glaciation at the time of its maximal development during the Pleistocene Epoch or to

the submergence of the continent under the weight of the ice-sheet (O. Nordenskjöld, 1913, F. Shepard, 1948; N. E. Odell, 1952).

Taking 180 metres as the difference in the slope of the shelves of Antarctica and the other continents, Odell calculated the average thickness of the continental ice-shield necessary for such depression and obtained 540 metres. Fairbridge, however, challenges the claim that the seaward subsidence of the shelf depends on the load of the ice-cap, pointing out that in this case the depression should be greatest in the centre of the continent and not on its outer margins. Odell and Fairbridge agree that nowhere in Antarctica are the signs of elevation resulting from the subsidence of the ice in any way comparable to those in the Northern Hemisphere. Raised beaches in Graham Land and Victoria Land, Fairbridge argues, are normal eustatic features, while Odell holds that they are signs of the rise of the continent.

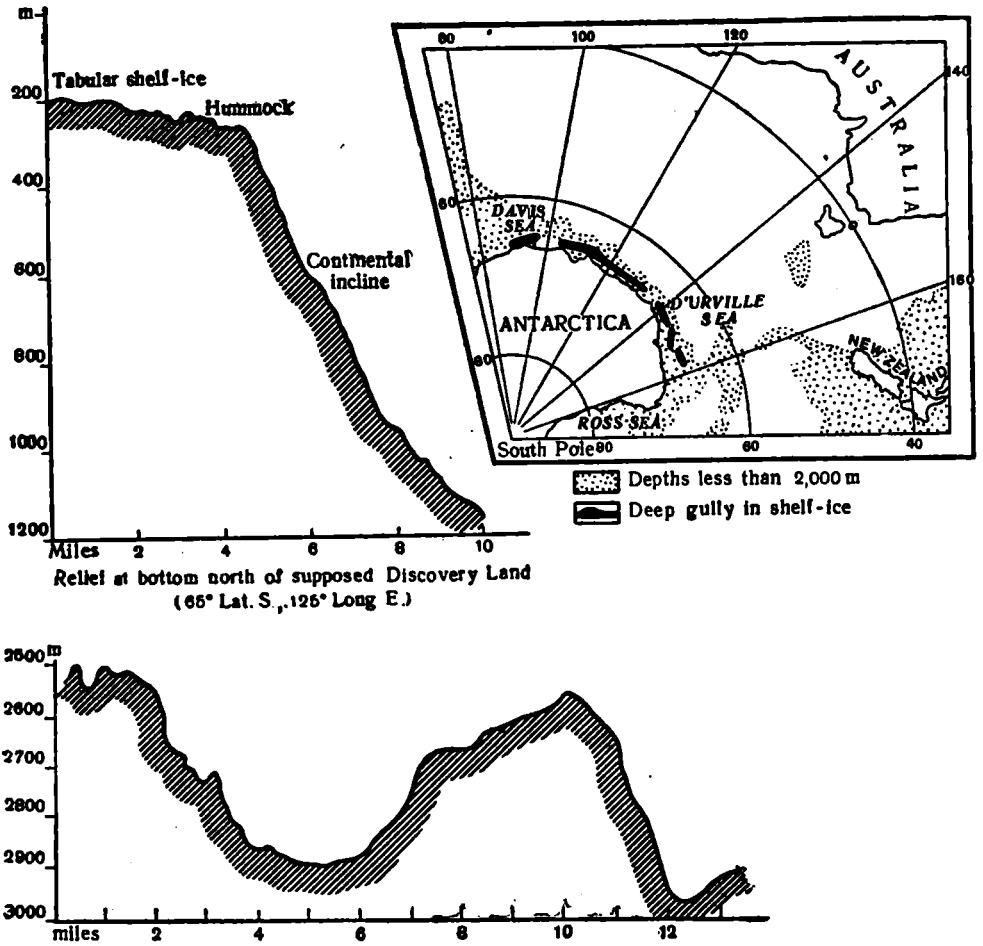
Some scientists regard traces of the fracture of the earth's crust as signs of the vertical movements of the continent which have been observed on the continental shelf In 1913, the *Aurora* discovered a broad moat 700 metres deep in the continental shelf off Adélie Land, while the *Discovery II* recorded a steep slope to a shelf edge of 450 metres. During their Antarctic expedition of 1946-47 the Americans obtained echo-traces of the continental slope which showed a concave profile 250 kilometres long.

The shelf also revealed traces of glacierization. In many places on the shelf edge there were morainal banks stretching in latitudinal direction.

Thus, Pennell Bank rises between 200 and 300 metres above the bottom of the Ross Sea.

Davis Bank stretches from the northern extremity of the Shackleton Shelf-Ice to the West Shelf-Ice, blocking the underwater exit from the Davis Sea.

Mawson Bank stretches along the continental shelf north of the Ninnis and Mertz glaciers.



Antarctic bottom relief off the coast (observations made by the *Ob* in 1956). The bottom diagram shows the nature of dissection of the continental shelf north of the D'Urville Sea (surveyed between 64°5I'S., 141°05'E and 65°03'S., 144°31'E)

No such elevations have been discovered in the southern sector of the Weddell Sea, but then very few sounding operations have been undertaken there.

Detailed topographical research off the Antarctic coast was carried out by the *Ob* expedition in the Indian Ocean sector in 1956. The results showed that there was no continental shelf there in the sense of a coastal plain sloping gently seaward to the depth of 150-200 metres. The surface there was extremely uneven and dotted with hummocks, and though it had a well-defined edge in profile where it

met the plateau surface, it nevertheless sloped 400 metres on the average.

Two morphological features were discovered within the boundaries of the shelf. The most widespread was the rugged shelf created by the uneven accumulation of the sediments carried from the continent by glaciers, glacial erosion at a lower level of the ocean, and greater glacierization. Extensive dissection of the shelf and the young character of relief forms off the coast testify, the participants in the expedition believed, to the recent submergence of the outer margins of the continent. The smooth shelf—in the shape of a gently sloping rolling plain—was discovered only on the periphery of the Shackleton Shelf-Ice and off Discovery Bank. In all the cases the shelf was separated from the continental slope by a very well defined edge. Narrow crevasses, of tectonic origin, stretching along the continent, were observed on the shelf, particularly on the coastline.

The most interesting feature of the continental shelf explored in the Indian Ocean sector was the wide moat between the coast and the edge of the shelf. This moat, first discovered by the *Aurora*, stretches for many miles along the coast and for most part is 700 metres deep, though in some places its depth exceeds 1,000 metres (there are parts 1,400 and 1,700 metres deep). Its breadth is from 20 to 60 miles. At the bottom, along the main axis of the channel, there are asymmetrical ridges and precipitous hollows. The *Ob* geologists believe that the moat entirely surrounds the continent and that it was formed by the fracture of the edge caused by Antarctica's vertical movements.

The multiformity of the moat, the sharp ridges and canyons are evidence of recent vertical tectonic movements. These movements, Soviet explorers say, are due to the changes in the Quaternary ice-load.

The average depth of the boundary between the shelf and the continental slope, according to the *Ob*'s survey, is 500 metres. The slope is a gradient with terraces rising to 600 metres.

The structure of the Antarctic Ocean floor is the result of glacial processes. Present-day glacial sediments—dumped boulders, clays and fluvio-glacial sands—form the first peripheral belt 1,000 kilometres wide. There is no doubt that there are pre-glacial deposits under the moraine, and the determination of their age is of considerable importance for the palaeogeographic reconstruction of the Antarctic region.

Beyond the belt of glacial deposits is the belt of cold-water ooze, mainly diatomaceous, whose zone was defined by the *Challenger* expedition (1872-76). The boundary of

diatomaceous ooze in the north runs roughly along the Antarctic Convergence. The distribution of ooze in the past permits us to judge how much the convergence has varied in position over the centuries. Short cores in this zone collected by the *Valdivia* and *Gauss* expeditions (1898-1903) revealed an unusual stratification of the sediments which suggests that there were cyclic periods during the Pleistocene when glacial influence waxed and waned. It was found that pelagic ooze of the diatomaceous and, farther north, globigerina types overlay the terrigenous deposits of blue mud.

Three-metre cores were obtained by the U.S. Antarctic expedition of 1946-47 north of the Ross Barrier. Radioactive age determination demonstrated conclusively the simultaneous development of Pleistocene climatic events in both Northern and Southern hemispheres, including the climatic optimum of 6,000 years ago.

The cores obtained by the Americans had been considered the longest until 1956, when the *Ob* obtained some 14.5 metres long. The analysis of these materials, however, has not yet been completed.

Beyond the diatomaceous ooze belt, whose boundary corresponds roughly with the northern limit of Antarctic surface water, the bottom consists chiefly of globigerina ooze, a sediment composed of the shells of the more or less warmth-loving pelagic foreminifera. In 1935, G. Schott drew attention to the fact that in cores with undisturbed stratification, obtained near the Antarctic Convergence, diatomaceous ooze lay below a thin veneer of globigerina ooze. This proves that in the last glacial phase the Antarctic Convergence was farther north. The sediments recently obtained, however, are not sufficient to determine the extent of the shifting of the Antarctic waters in the past. The solution of this problem requires further research.

A characteristic feature of both the Antarctic and north polar cores is the low percentage of calcium car-

bonate in recent sediments, a fact due to low temperature. The calcium carbonate content in earlier sediments, as we shall see below, plays a big role in the palaeogeographic study of the Antarctic.

Most of the Antarctic islands formed in the Tertiary period and are almost entirely made up of volcanics, although there are sediments too. The significant feature of these islands is their short life. Winds and storm waves abrade the volcanic cones of these islands, making them asymmetrical. Islands in the West Wind Drift have precipitous cliffs in the west and south, and gentler eastern slopes. Fleming describes the destruction process of the Antarctic islands—from the abrasion of their volcanic cones to the formation of 100-metre submarine slopes—and calls these islands ephemeral formations that have to renew their crumbling edifices by a rebirth of volcanism or by upheaval.

GEOLOGY AND MINERAL RESOURCES

From a seismic point of view, the whole of Antarctica is stable, although in some regions there are volcanic formations of recent origin.

British and American surveys in the Ross Sea and Soviet exploration in the Davis Sea show that earthquakes with northern epicentres are quite frequent on the coast.

Opinions vary on the age of the region's geological structure. And there are no fewer arguments about the age of the submarine relief.

According to Bourcart (1953), the bottom of the Antarctic Basin is depressing, while the flexure of the ice-shield is increasing. Prior to the Tertiary period the altitude of the continent was much lower and the Southern Ocean was made up of two seas: the South Pacific (off the Ross Sea) and the Agulhas (off South Africa). For a diametrically different opinion we may quote Vallaux, who claimed (1948) that the Southern Ocean had always existed.

There is, apparently, good reason to believe that the Pacific sector on the whole is of pre-Cambrian age, although Tertiary folds and faults had caused many changes in its structure. The Indian Ocean sector is younger, whereas the Atlantic is of mixed origin with major traces of recent volcanic activity. In recent years scientists have established that there is much that is common in the geological structure of the Antarctic regions and the adjacent areas of South America, Africa and Australia, especially as regards the distribution of the deposits of Gondwana type.

One of the notable features of the Antarctic Continent is its great altitude. The following interesting comparison was made by Buinitsky in 1953: the average altitude of Eurasia is 830 metres, Australia—340, all the continents minus Antarctica—725 metres, and Antarctica—2,200 metres. Proceeding from meteorological data, Fairbridge (1952) claims that it is even greater, 2,400 metres, to be exact, while D. I. Shcherbakov (1956) gives the figure as 2,250. This high altitude is undoubtedly due to the ice-sheet. Nothing is known of the continent's altitude under the ice. The figure given by Fairbridge in 1952 is 1,000 metres, Bauer (1955) says it is 630 metres, while in 1957 scientists were inclined to think it was still less.

The diversity of Antarctica's geological structure, though studied very little, permits the division of the continent into two diametrically different parts—eastern and western.

East Antarctica is the pre-Cambrian nucleus of the continent and is considered to be an extension of the continental masses of South Africa and Australia, that is, of the Gondwana land countries.

West Antarctica is younger. It is formed by the Antarctic Andes, which are an extension of the Andes of South America and stretch farther on to New Zealand and Australia.

The zone between the western and eastern parts of An-

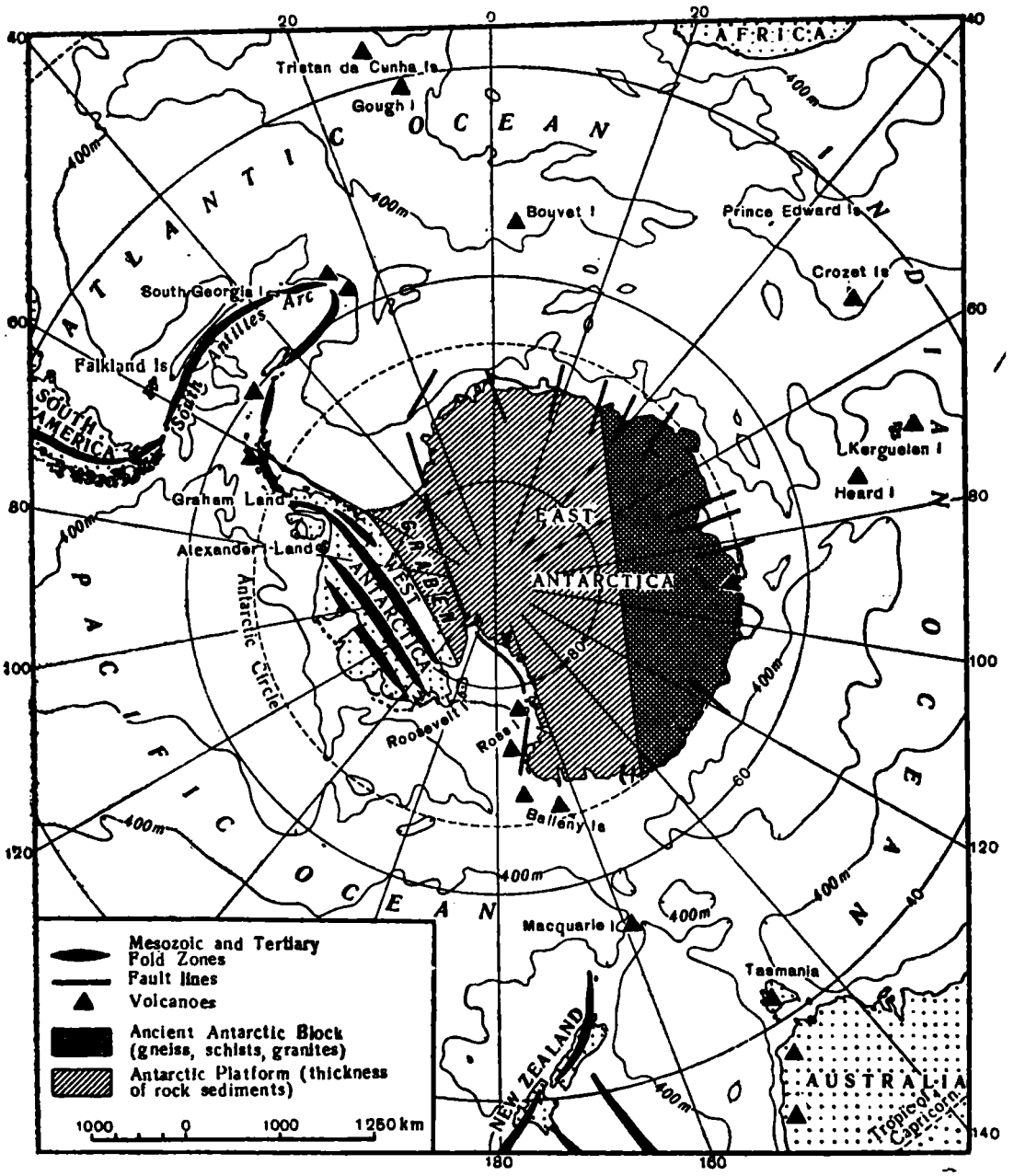
arctica, joining the Ross and Weddell seas, is a belt of ubsidence called the Ross-Weddell Graben. It is quite possible that there is a canal, an inland sea or a deep bay under this 800-kilometre-wide and 3,200-kilometre-long graben.

According to the latest works of Fairbridge, Panov and Shalimov, the general outlines of Antarctica's structure and geology are as follows:

EAST ANTARCTICA—divided into two parts: the Antarctic shield of Archaean age, occupying the greater part of the area, and the South Polar Plateau between the Ross and Weddell seas. The boundary between these structures passes along the line of Palaeozoic and Triassic sediments and is quite conventional, since there are outcrops only in the coastal regions (the rest of the continent is covered by a thick ice-sheet). That is why certain geologists believe that the Antarctic shield stretches only along the coast. Inland, the shield may have subsided under the weight of rocky sediments.

The Antarctic shield consists of pre-Cambrian gneisses, schists and granites. By its composition, the degree of metamorphism and the intensity of granitization and magnatization, this crystalline complex is very much like the Archaean complex of India, Australia and Madagascar. On the coast there are signs of fracture in the shield and uneven displacement of its parts. Tertiary faults were attended by volcanic activity creating basalt and tufaceous earth crust (Queen Maud Land) and volcanic cones like Mount Gauss.

From the Adélie Land-Princess Ragnhild Land line towards the Ross-Weddell Graben, the Archaean sediments of the Antarctic shield are overlaid by horizontal sediments consisting of strongly metamorphosed Cambrian limestone and thick layers of Beacon Sandstone (Upper Devonian-Trias), which crowns the mountain ranges in Victoria Land over a 2,000-kilometre stretch. The thickness of sandstone in these parts ranges from 600 to 1,700 me-



Tectonic sketch-map of Antarctica (after R. Fairbridge, 1952, and D. G. Panov, 1951, with modifications)

tres and that shows that in late Palaeozoic the region subsided as much as 2,000 metres. The series consists of arkosic and quartz sandstones, intercalated with lignite. The coal, Gondwana plant fossils, ripple-marks and sun-cracks are evidence of the continental and shallow-water character of the sandstone. Horizontal sediments include also dolerite sills of Upper Trias and are overlaid by Cainozoic basalts. Such a structure of the region made it possible to regard it as a plateau which has come to be known as *South Polar Plateau.*

In the Tertiary period the homogeneous structure of the South Polar Plateau underwent fracture. The result was the formation of the Antarctic Horst (Victoria Land) and the adjacent Ross depression. The subsidence of the continent's edge was attended by intense volcanic activity which brought about into being a chain of volcanoes (the biggest is the Erebus) on the boundary of the horst and the depression.

The continuance of the Antarctic Horst in the Atlantic sector is in the Queen Maud Range.

WEST ANTARCTICA, or the Antarctic Andes[1], stretches from the western coast of the Ross Sea to Graham Land. The Antarctic Andes are apparently formed mainly of Mesozoic deposits and volcanics of Alpine age.

The central part of the region, Marie Byrd Land and Ellsworth Land, has never been explored geologically. There is not a single sample available. Observations have been made only from the air. The Antarctic Andes in Graham Land consist of Jurassic, Cretaceous and Tertiary sediments. The age of the Antarctic Andes, off the Ross Sea coast—Edsel Ford Mountains—is not known because no organic remains were found there. Chemically, the magmatic intrusions in these two regions are essentially different, although Fairbridge includes the above-mentioned mountains

[1] According to Fairbridge, the Antarctic Andes system does not include the mountains in King Edward VII Land which, possibly, belong to the Caledonian fold type.

in the Alpine system. Most of the islands off Graham Land are covered with late Tertiary-early Quaternary lava. The Antarctic Andes are a chain of high fold mountains, with crevasses in many parts. Some of the peaks are over 6,000 metres above sea-level.

The West-Antarctic mountain ranges are connected with the South-American Andes by a submarine ridge (the Antilles Arc). In length (about 4,000 kilometres) and height (up to 6,000 metres from its floor), the ridge is not inferior to the Andes. The central part of the arc is highly seismic. The South Antilles Arc, it is assumed, formed in the Alpine period.

The Ross-Weddell Graben is the least known region of the continent. The geological structure of its Pacific edge permits assumption that it is a zone of subsidence and accumulation of late Palaeozoic-early Mesozoic sediments. Fairbridge is of the opinion that in some places the Beacon Sandstone in this depression is 3,000 metres thick. The graben is cut off from East and West Antarctica by faults from 6,000 to 7,000 kilometres high.

The Antarctic's *mineral resources* have been very little explored despite the keen interest they arouse the world over. The most important discovery so far has been the quartz-pyrite vein in the South Shetlands. The deposits, it is believed, amount to many thousands of tons. There are also deposits of high-quality anthracite and a small quantity of copper ores. Traces of silver, gold, manganese ore and molybdenum, as well as of copper, have been found in Graham Land. Lead and iron have been discovered in Marie Byrd Land and it is assumed that there are coal deposits in Alexander I Land (Christie, 1951).

Geologists believe that the eastern part of Antarctica is richer in minerals. Here, just in the other Gondwana continents, there are probably rich deposits of uranium, thorium, gold, iron and manganese ores. The *New York Times* reported on April 29, 1957, that American Antarctic explorers had found a rich manganese ore vein (3.6 metres

in diameter), containing between 60 and 70 per cent of manganese. There were also traces of copper ore in the same place. Copper ores, molybdenum, lead and other valuable minerals have been found in King George V Land. The most important deposits, however, are those of anthracite in Victoria Land. These coals have been traced to extend more than 3,200 kilometres and are closely comparable with Australian Permian coals (Fairbridge, 1952).

CONTINENTAL ICE

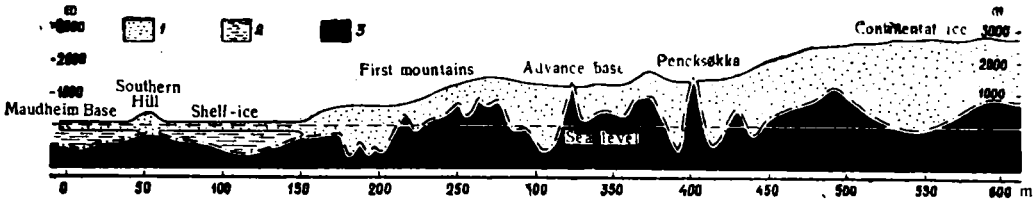
ICE-SHEET

With the exception of a few "oases" and the highest mountains, the whole of the Antarctic Continent is submerged under a thick mantle of ice, which also extends to many parts of the continental shelf. The total area of this ice-sheet exceeds 14,000,000 square kilometres.

It is extremely difficult to determine the thickness of the ice over such a vast expanse with the aid of instrumental technique. It was only in 1949-52 that the Norwegian-British-Swedish expedition operating in Queen Maud Land measured the thickness of ice on a 600-kilometre stretch in East Antarctica. Other measurements were chiefly carried out in West Antarctica, whose structure is very much different from that of the rest of the continent. With no suitable instrumental technique available, scientists make wide use of postulated calculations of the thickness of the Antarctic ice-cap.

In 1879, James Croll calculated that the ice-cover at the South Pole would have to be anything from seven miles thick in order to give sufficient inclination to cause outward flow. It was only recently that this estimate finally found support among scientists. The well-known physicist G. Robin wrote in 1953 that Croll's figures and the factors he considered necessary for the flow of ice roughly coincided with present-day assessments.

Sir Douglas Mawson, who carried out magnetic survey in East Antarctica in 1909-12, came to the conclusion that



A) Seismic profile of Queen Maud Land
(Norwegian-British-Swedish Expedition, 1949-52)
1—Ice, 2—Water, 3—Rock

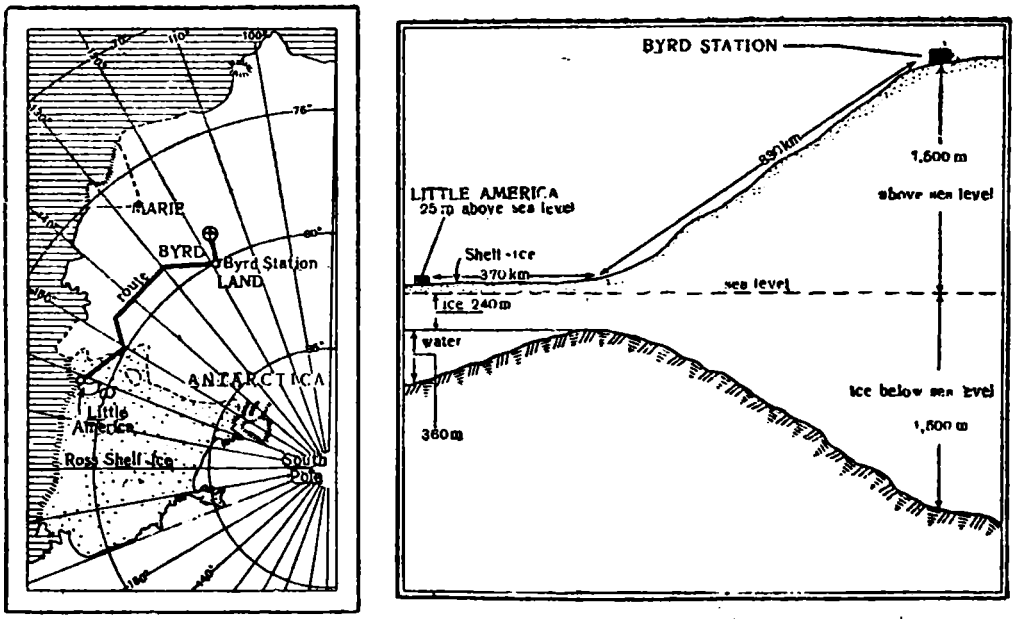
the ice-sheet in the vicinity of the magnetic pole was thin, since, if it were thick, the variations in magnetic declination would be weaker. Meinardus, on the other hand, suggested a different way of assessing the thickness of the ice-sheet. The ice surface of Antarctica is considerably higher than that of the other continents and this difference, it may be said, is created by the thickness of the sheet (1,500 metres).

The glaciologist N. E. Odell, making his calculations on the basis of the depth of the continental shelf in 1952, suggested that the ice-sheet was approximately 540 metres thick, but the principle of such assessment has been challenged by many scientists.

Analyzing the materials of the Scott-Shackleton expedition, Wright and Pristley (1922) came to the conclusion that the depth of the ice in the area where the expedition operated nowhere exceeded 600 metres.

Instrumental measurements of the thickness of the ice-sheet in West Antarctica have been carried out in recent years by British and American explorers. Seismic soundings in King Edward VII Land reveal that the maximum ice-thickness there is about 630 metres.

Measurements carried out by the Norwegian-British-Swedish expedition in Queen Maud Land showed that ice there was of variable depth (from 300 to 800 metres and more), and that would indicate a rugged topography of the rock-floor. The greatest thickness of the ice measured was 2,200 metres in the interior of the continent. The sur-



B) Seismic profile of Marie Byrd Land (American expedition, 1956-57, as given by the *New York Times* of December 30, 1956, and May 5, 1957)

vey, undertaken in the area between 71°02.6′ S., 10°55.5′ W. and 74°15′ S., 0°, revealed that there were bays 1,000 metres deep submerged under the ice and that the area apparently was an ice-covered archipelago.

Ice measurements in East Antarctica have latterly been carried out by Soviet scientists in Queen Mary Land. Seismic soundings in 93°E., some 400 kilometres inland, showed that the rock-floor in this sector was generally below sea-level. The depth of the ice ranged from 165 to 2,250 metres, while the maximum thickness was 3,500 metres at the 375th kilometre.

The volume of ice per one kilometre from the edge of the coastline to the 200th kilometre inland was 260 cubic kilometres.

These data should bring considerable changes into the assessment of the average thickness of ice (which the expedition assessed in 1956 at 1,500 metres) and of its volume (which was considered close to 17,000,000 cubic kilometres).

On May 5, 1957, the *New York Times* carried the first report on seismic soundings along the 632-mile stretch from Little America to Byrd Station. These observations, checked by gravimetric measurements, revealed that the thickness of the marginal continental ice near the Ross Barrier at 80°S. and 150°W. was 600 metres, gradually increasing to 3,000 metres in the Byrd Station area where the rock-floor was 1,500 metres below sea-level. Illustrating the report with a seismological scheme (see Fig. on p. 66), the paper recalled R. F. Flint's claim that the load of the ice-sheet may depress the rock-floor to a depth equal to one-third of the ice-cover's thickness. Proceeding from a comparison of the specific weight of the ice and rocks, Flint is of the opinion that the rock-floor of the ice-sheet in the Byrd Station area will not rise to the level of the sea even if the ice were to melt completely.

Continental ice is divided into two main types: *glacial* and *shelf*. The first is a field or stream of ice formed on land. Shelf-ice is an extensive fresh-water ice-sheet originating on land and continuing out to sea, but usually connected with the coastal glaciers and partly fed by one or several of them. Some of them are afloat, the movement of others is obstructed by shoals.

The difference in the structure of glacial and shelf-ice is not always well defined. It is best reflected in the two diametrically different types: the glacier rapidly moving seaward across the mountainous coast and the almost static shelf-ice enclaved within a gulf.

In the first instance, the ice carried from the interior of the continent may be of ancient origin, that is, in many cases it is what remains of the mighty ice masses dating to the latter period of the glacial epoch. The three factors conditioning the accumulation of ice in the interior of the continent are: insignificant precipitation, the complete absence of the melting process and the extremely low temperature the year round. The main features of the monolithic ice masses forming here are ill-defined stratification

and low content of air. In their advance seaward across mountainous regions, glaciers sometimes develop crevasses and become choked with moraine. The surface of the ice becomes irregular, its stratification is deformed by flexures, fractures and regelation.

Shelf-ice presents a completely different picture. Ice accumulates in conditions of comparatively abundant precipitation, subject, of course, to seasonal fluctuations. Snow covers the surface with even strata, the uppermost of which is exposed to short seasonal melting processes. The result is accumulation of horizontal layers of firn (névé) and young ice with a high content of air and free from foreign matter. On floating shelf-ice snow accumulation is attended by its melting and erosion underwater.

The examples cited above are typical of the clearly defined properties of the glacial and shelf-ice forms. There are also various transitory forms: with time the upper layers of shelf-ice can acquire a monolithic glacial structure, while glaciers accumulate new strata of ice as they reach the coastal zone of abundant precipitation.

In American polar literature Antarctic glaciers are subdivided into various types. The *continental glacier* is part of the comparatively rapid-moving ice-sheet covering the coastal slopes. The *valley*, or *mountain,* glaciers are the ice-streams that take their source in alpine regions and move seaward along well-defined valleys or fjords. Valley glaciers, on their part, are subdivided into *outlet glaciers* which, thrusting over mountainous terrain, connect the ice mass in the interior with the shore; *transaction glaciers* which, moving across watersheds, connect neighbouring ice-streams; and *dendritic glaciers* formed by the coalescence of sidestreams. Besides, there are *wall-sided glaciers* which originate in upland regions, flow down unconfined by any valley wall and move over moraine. Glaciers are active or stagnant, with the wall-sided glaciers belonging chiefly to the latter category.

The *expanded foot* of a glacier is the part spreading out beyond a mountain valley, usually on an unconfined plain or a strand. An *ice fall* is a fracture in the surface of a glacier, caused by a sharp incline in its channel and creating steep and precipitous deformations on the surface of the ice.

There are two types of glaciers formed by ice-streams as they reach the coastline: the *confluent ice*, resulting from the coalescence

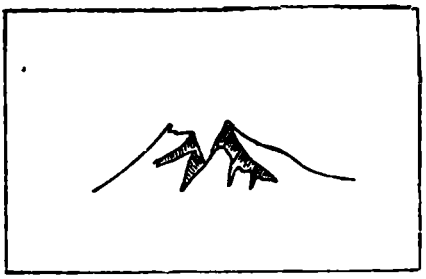
of several glaciers whose sea edges are connected by a barrier of coastal islands, and the *Piedmont glacier*, which is a vast coastal ice-sheet fed by one or more valley glaciers. It may be partly afloat and partly aground.

As they reach the shore, glaciers project into the ocean numerous ice-tongues, the biggest being the Ninnis and Mertz ice-tongues on the same meridian with Tasmania. Both emerge from vast fjords. The Mertz Ice-Tongue protrudes 80 kilometres into the sea and is about 37 kilometres wide and 61 metres high, while the Ninnis Ice-Tongue is almost 135 kilometres long, from 22 to 45 kilometres wide and 53 metres high. Its nothernmost extremity curves westward and that may be attributed to the bottom relief.

The stability of this gigantic ice-tongue is quite a mystery. Professor N. Zubov holds that this is due to the fact that the greater part of the glacier lies in shoal-water. As far as it is known, no measurements of depth have been carried out there.

The glaciers debouching into the sea off the western shore of Graham Land are of an absolutely different type. Their coalescing feet form an ice-sheet tens and hundreds of metres wide along the mountainous coastline. At the edge, these glaciers drop from 5 to 70 metres, though more often from 25 to 30 metres. The British geologist W. L. S. Fleming calls them "marginal" glaciers. They usually slope gently seaward and their surface is crevassed.

Shelf-ice masses, or barriers, are peculiar to Antarctica. Stretching out over vast territory, they jut out hundreds of kilometres into the sea. The Ross Barrier, in the southern part of the sea of that name, is about 500,000 square kilometres in extent. Wright and Pristley estimate the average thickness of the ice-sheet at about 240 metres, while Gould thinks it may be as much as 330 metres. The outer edge rises 50-60 metres above sea-level. The average height of the barrier is variably estimated at between 50 and 70 metres, with some elevations rising from 100 to 300 metres.



An ice hill on the Ross Barrier (Frank Debenham)

The two other giant shelf-ice masses—Larsen and Lassiter—are in the western and eastern parts of the Weddell Sea. They have been explored less than the Ross Barrier, but the survey done shows that physically they are quite different from the ice mass in the Ross Sea, and sometimes they are placed into a category of their own. In the Indian Ocean sector are the huge Shackleton Shelf-Ice and West Shelf-Ice. The former stretches 165 miles along the coast and projects 150 miles into the sea. Its surface is generally flat, though in some places it rises about 30 metres and is cut up by crevasses. The Antarctic Expedition of the U.S.S.R. Academy of Sciences discovered little blue lakes, streams and rivers flowing into the ocean. The outer edge of the shelf-ice is between 18 and 30 metres above sea-level.

The West Shelf-Ice, also called Drygalski Shelf-Ice, is a relic of the glacial epoch. It is some 50 metres high.

Scott, David and Pristley (1914) believed the Ross Barrier to be a floating piedmont, and its ice supplied by the peripheral glaciers. Later, Pristley granted a larger role to the accumulation of snow upon a raft of sea-ice.

Nordenskjöld (referring to the Larsen Shelf-Ice) and Gould (speaking of the Ross Barrier) pointed out that a major factor in the nourishment of barriers was the precipitation of snow upon their surface. Wade (1945) concluded that the barrier ice was kept in existence today chiefly by the accumulation of precipitated snow, and said that the coastal glaciers played a secondary part. Professor Zubov considers that it would be more proper to call the Ross Barrier, Lassiter Shelf-Ice and similar glaciers "bay-fast" ice shelves.

Buinitsky (1953) believes that the base of the Ross Barrier is formed of inland ice.

Its northern part is afloat and, most of the authorities agree, its wastage is due largely to the melting on the under-surface. Since no changes in the barrier's level have been observed, it may be assumed that this wastage is more or less proportional to snow accumulation. In his day Scott drew attention to the vast volume of water passing in and out beneath the ice-sheet at every fall and rise of the tide, and this would seem to contribute to the destruction of its underwater part.

Until recently there had been very little data permitting correct assessment of the role played by precipitation and land ice in the maintenance of shelf-ice masses. A study of the structure of the Shackleton Shelf-Ice was made in 1956-57 by Soviet scientists, who found that this formation at least was nourished mainly by precipitated snow.

Survey done on the Maudheim Shelf-Ice in 1950-51 produced some very valuable data on its volume. The scientists studied changes in a 14.9 square-kilometre triangular polygon marked with aluminium rods. As a result of the Maudheim's movement, the area increased by 12,200 square metres in six months. The level of the shelf-ice remained unchanged (from 1950 to 1952 the change in level in the centre amounted to only one centimetre while the accumulation of snow was 170 centimetres). Taking into consideration its isostatic equilibrium in water, the scientists estimated the thickness of the shelf-ice at 185 metres. They thus determined the increase in the volume of ice on the polygon: 2,260,000 cubic metres. The average density of the shelf-ice was estimated (by extrapolarization) at 0.84. Hence, in terms of water the increase in the volume of ice was equivalent to almost 1,900,000 cubic metres. The average accumulation of snow in that same period (based on measurements at 14 stations) was 2,830,000 cubic metres. It was thus established that the increase in the ice mass through accumulation considerably exceeded its decrease by ablation. Consequently, about one-third of accumula-

tion should be compensated by melting on the under-surface of the shelf-ice. In the Maudheim region such melting will produce annually a 14-centimetre layer of water.

At any rate, tidal activity, melting and accumulation of snow constantly disturb the equilibrium of the shelf-ice. Gould, who did research work on the Ross Barrier in 1930, has this to say: "It appeared that even though the shelf-ice is here at least 700 feet thick, it was under such a great strain that even the weight of our outfit was enough to disturb its equilibrium and start it cracking" (A. Scholes, *Seventh Continent*, London, 1953). There are at present fifteen crevassed sectors on the Ross Barrier, some of them more than 400 kilometres from the sea.

Survey at Maudheim showed that "marginal" crevasses, caused by tides and dividing the floating part from that lying on the shelf, were a characteristic feature of the ice shelves. Hence the conclusion that ice shelves can exist only if they are held together by islands and shoals.[1] In this respect, shelf-ice charts are very convincing. Another conclusion arrived at by the Maudheim expedition is that it is quite possible to determine if there are any shoals by the configuration of the edge of a shelf-ice. If it is aground, its edge is smooth; if it is afloat, it is irregularly dissected.

Frank Debenham, the geologist with Scott's expedition of 1910-12, was one of the first to describe in detail and explain the hummocks created by the distention and rupture of the ice surface on the Ross Barrier (see Fig. on p. 70) According to Debenham, they were between two and three metres high. Hummocks about 0.9 metre high and three metres in diameter were found and surveyed by American scientists on the T-3 ice island in the Arctic Ocean in 1952. A detailed theoretical analysis of the formation of hummocks has been made by Professor Zubov.

They are created, he says, by the distention and rupture of water pockets—pools that form under the ice as the

[1] Were it otherwise, they would break away along the crevasse and drift into the sea.

lakes freeze. Sometimes a lake is blanketed so heavily with snow in winter that it does not melt in summer and another lake forms on top of it. Thus, abundant precipitation may form a whole series of water pockets one on top of another.

Water pockets are characteristic of both the land ice and sea ice of the Arctic and Antarctic. They are especially widespread in the Davis Sea, as discovered in 1956 by the Soviet Antarctic Expedition's glaciologist team, headed by V. S. Nazarov.

In some parts of the Antarctic snow accumulates and solidifies extremely rapidly. From 1941 to 1947 the Little America barracks were buried under a thick mantle of snow. The bottom 120 centimetres had turned into semi-transparent névé which let daylight through (T. R. Henry, *The White Continent*, N. Y., 1950, p. 157).

One of the members of the American expedition, Dr. Thomas Poulter, sank a two-metre shaft in the shelf-ice. Holding his palm 30 centimetres over the aperture he could feel the air current rising from the shaft. Poulter attributed this phenomenon to the condensation of ice crystals.

The growth of these ice crystals and the condensation of névé and ice on the Ross Barrier sometimes cause snow-slides. The interesting point is that although these snow-slides, sometimes also called "snow-quakes," affect large areas and cause loud detonations, the level of snow as a rule decreases only by a few centimetres.

Reports on surveys of the speed and character of the movement of glaciers and ice shelves in Antarctica, as well as on glaciation, have been studied very little. Theoretically, these questions have yet to be solved.

Observations in the Northern Hemisphere have shown that glaciers do not descend at uniform speed—the speed intensifies from the edges to the centre. Vertically, in accordance with the law of parabolics, the speed gains momentum from the rock-floor to the surface. Such distribution of speeds, caused by the plastic motion of ice, is at times disturbed by descending blocks.

Glaciation is also determined by the plastic properties of ice under heavy pressure. The profile of equilibrium of a plastic body is not the horizontal line as in the case of viscous bodies, but a convex curve. Observations in Greenland revealed that, vertically, the continental sheet is shaped like the arc of an ellipse with a transverse axis. We may assume that this more or less applies to the Antarctic sheet too, though its shape is somewhat complicated by the uneven accumulation of snow. The ellipsoidal form of equilibrium is constantly disturbed by ice debouching at the margin of the continental sheet and continually re-established by the stream of inland ice.

Theoretically, the law governing the preservation of the form of equilibrium by a plastic body should apply to the motion of shelf-ice just as it applies to the continental sheet. The form of equilibrium of a floating shelf-ice, however, is influenced to a certain degree by the hydrostatic pressure of water on the barrier and the isostatic tensions arising in a floating body of uneven thickness.

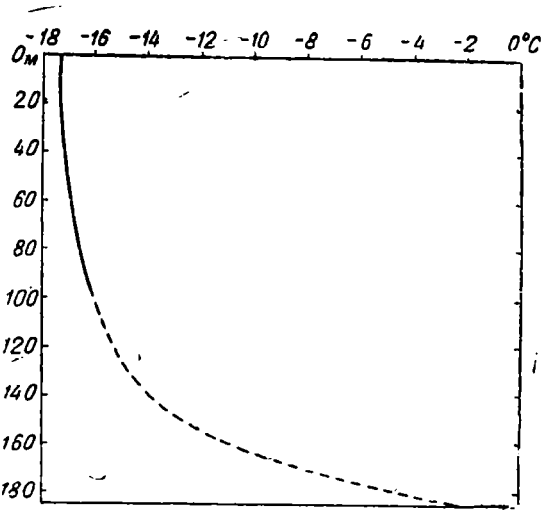
Very little is known of the épure of shelf-ice movement. Some observations were made by glaciologists at Maudheim where they bored down to 100 metres, but these did not reveal any noticeable changes in speed. On the surface, the seaward motion was in the order of 300 metres per annum.

The claims regarding the movement of the Ross Barrier are rather contradictory. F. Wade (1945) thinks it is virtually static, or moves northward at about one metre a year. Other explorers say the barrier moves between one and four metres a day, varying with the position nearer in-shore, or farther off-shore. Gould too regards these figures as conservative. Measurements made by the Byrd expedition revealed that from 1941 to 1946 Little America had moved 2,780 metres northwest, or, in other words, at a speed of slightly over 550 metres a year.

Very little has been done to determine how fast Antarctica's glaciers move. Judging by the displacement of one of Scott's storehouses, the continent's biggest glacier, Beardmore, moves 494 metres per annum. To reach the sea across the Ross Barrier would take it about 1,200 years (*The Antarctic Pilot*, London, 1948, p. 37). The Barrier gets approximately half a metre of precipitated snow a year,

and thus in the process of its movement land-ice should be completely replaced by shelf-ice.

The speed with which ice moves in the area of Mirny decreases markedly inland. On the coast it is 250 metres per annum, 10 kilometres inland (according to Shumsky)—83 metres, 200 kilometres inland —17. Thus, at this last point, the supply of ice by glaciers is still greater than accumulation.



Distribution of temperature at depth at Maudheim. The broken line is the result of interpolation (after V. Schytt, 1954)

Of great value to the study of the structure of land- and shelf-ice are shafts and borings in the ice. Operating in Queen Maud Land, the Norwegian-British-Swedish Expedition (1949-52) bored down to 100 metres. One of the members of the expedition, Valter Schytt, writes that the density of shelf-ice at 60 metres was 0.82.

As is known, air bubbles in the ice are separated from one another, while in the névé they communicate with one another. Studies in the Alps have shown that this communication occurs in densities from 0.82 to 0.84. These figures, it turns out, are not typical of the Alps only, for similar results were obtained at Maudheim, where ice is of the polar type of high altitudes. It was thus determined that the névé can be found at the depth of 60 metres.

In the course of their survey on the Ross Barrier in 1941, the Americans sank a shaft seven metres deep. In 1947, it was discovered that as a result of the 6-metre-thick accumulation of precipitated snow on the surface the ice had compacted and the depth of the shaft itself decreased between 1.5 and 2 metres. In 1941, the American research-

ers carved out round holes in the walls of the shaft. In 1947, it was found that these holes had become elliptical in shape, especially those carved out near the surface. The Americans also studied ice crystals at various depths. All these tests, they said, show that glacial ice can form "on the spot" on the shelf-ice, without having to be brought from the continent.

The density of the ice on the Ross Barrier was obtained only to the depth of 10.7 metres and was 0.64. Proceeding from the rate of névé condensation, Howard calculated in 1948 that the density of 0.84 could be obtained at a depth of approximately 30 metres. And that is approximately the maximum depth of the névé.

The reports of the Soviet Antarctic expedition, which had sunk shafts up to 102 metres deep, say that there are apparently no névé layers along a 500-metre stretch of the continental fringe in the Mirny area. This is probably due to weathering and the action of dry mountain winds. As one proceeds 500 metres and more inland, the thickness of the névé layer increases to several score metres.

Shafts are also invaluable for the study of shelf-ice temperatures.

It is generally known that the temperature on the surface of the ice-sheet differs very little from the negative temperatures of the air (by 1-3°) and is 0°C. when the temperature is positive. Fluctuation in the temperature of the ice becomes rapidly less below the surface. According to numerous observations and the thesis propounded way back in 1876 by P. A. Kropotkin, at a certain depth of the shelf-ice the temperature is permanently close to the annual mean temperature of the air.

Thus, on the Ross Barrier in 1941 the temperature of the ice at 15 metres was minus 23.2°C., while the mean annual temperature of the air was minus 23.6°C.

At Maudheim in 1949-52 ice temperature was taken regularly with a platinum thermometer in a shaft 100 metres

deep. Fluctuations in the temperature on the surface were just as considerable as in the air, but at the depth of five metres they decreased to about 4° and at the depth of 20 metres to slightly over 0.03°. The temperature of the ice at this depth was close to minus 17.2°C., rising constantly as the depth increased to minus 16.2°C. at 100 metres (see Fig. on p. 75). At a point 300 kilometres south of the Maudheim base the temperature of the ice in the layer (which is not subject to seasonal fluctuations) was minus 30°C., at 600 kilometres it was minus 40°C.

In the névé of Antarctica's narrow coastline the temperature at the depth where seasonal fluctuations cease is usually slightly above the mean annual temperature of the air, and that is due to the warmth brought in summer by the melt-water. In the shaft sunk in the Mirny area to the rock bottom of the glacier (86 metres) the temperatures on November 19, 1956, were: at two metres—minus 11.8°C., at 10 metres—minus 9°, at 20 metres—minus 8.5°, at 47 metres—minus 7.4°, and at 86 metres—minus 5.8°. The mean annual temperature at Mirny is minus 10.2°C. At a point 52 kilometres south of Mirny the temperature of the ice in the layer was minus 19°, 150 kilometres—minus 27°, 375 kilometres—minus 39.5°.

P. A. Shumsky's glaciological party established in 1957 that on the stretch between the Mirny and Pionerskaya stations the temperature of the ice did not rise at depths below 15 metres (as is the case in the Mirny shaft), but dropped on the average by 1° per 89 metres (the observations were made in a shaft 102 metres deep). Shumsky explains the drop in the temperature by the influx into the depth of colder ice, from the central parts of the continent.

For cases where there is no influx of ice or melt-water Professor Zubov in 1956 suggested a formula of interdependence of the thickness and temperature of the glacier.

The thickness of the glacier, whose temperature at the bottom is

equal to the temperature of melting ice, is critical, according to Professor Zubov, who defines it by the following equation:

$$q\,\text{crit.} = D + \frac{c\,(Q - t)}{q}$$

where D is the density of the active layer of ice subjected to seasonal fluctuations in temperature, c is the coefficient of the heat conductivity of the ice, $Q - t$ is the difference in the temperature at the surface and bottom of the glacier, q is the influx of sub-soil heat.

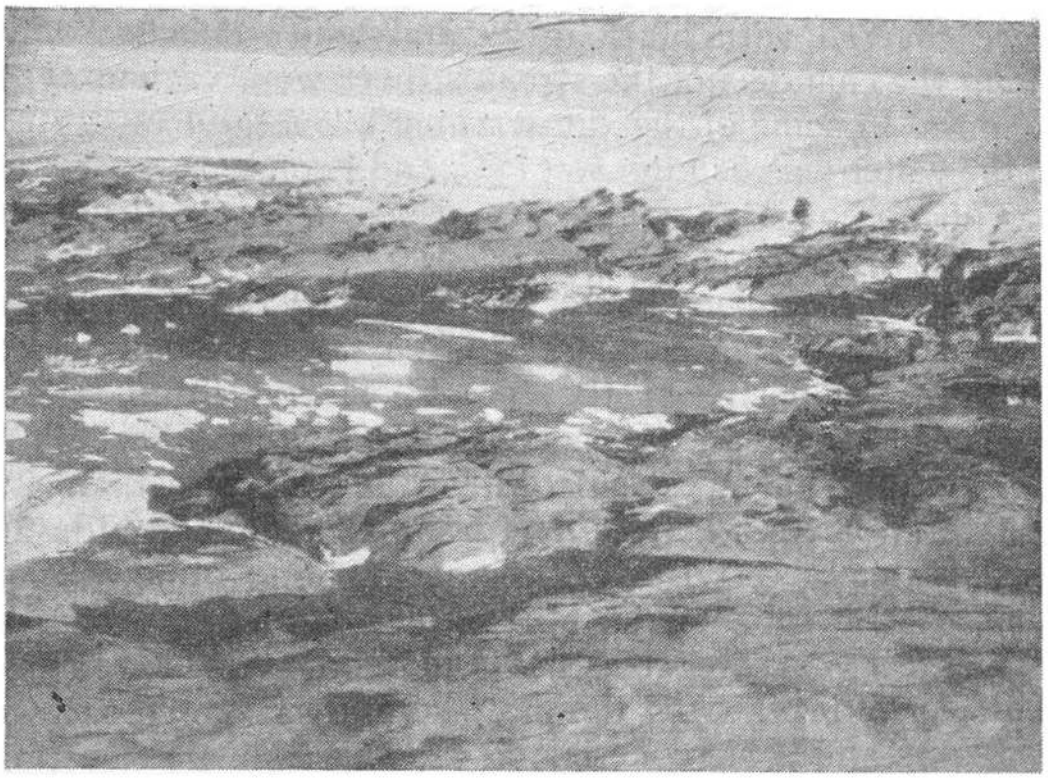
Professor Zubov points out that the earth freezes when the thickness of the ice is below the critical stage and that the ice melts if it is above that stage.

If we assume that the average thickness of the Antarctic ice sheet is not below 1,500 metres and the annual mean temperature of the air over it is not below minus 50° C., then we can deduce from the formula that the freezing of the glacier's rock bottom is not typical of Antarctica.

"OASES"

The discovery in the Southern Continent of "oases," that is, patches of ice-free land, has evoked keen interest in the world of science. Several of these "oases" were found in 1946-47 by the Byrd expedition, the biggest off the eastern part of the Shackleton Shelf-Ice. First seen from the air in 1947 by Lieutenant-Commander David Bunger, who took off from the tender *Currituck*, this elongated 750-square-kilometre "oasis" (later named after its discoverer) is surrounded by ice rising steeply to 30 metres on two sides and sloping on the third. Abutting in the north on the ice-encumbered coast, the "oasis" is a conglomeration of brown, snow-free hills and numerous blue and green lakes.

Early in February 1947, Bunger succeeded in landing his seaplane on one of the lakes. The microscopic brown, red and blue-green seaweeds, he found, lent a bright colouring to the lakes. North of the coastal ice mass was a 30-kilometre-wide patch of unfrozen water and beyond that an ice pack about 150 kilometres in length.



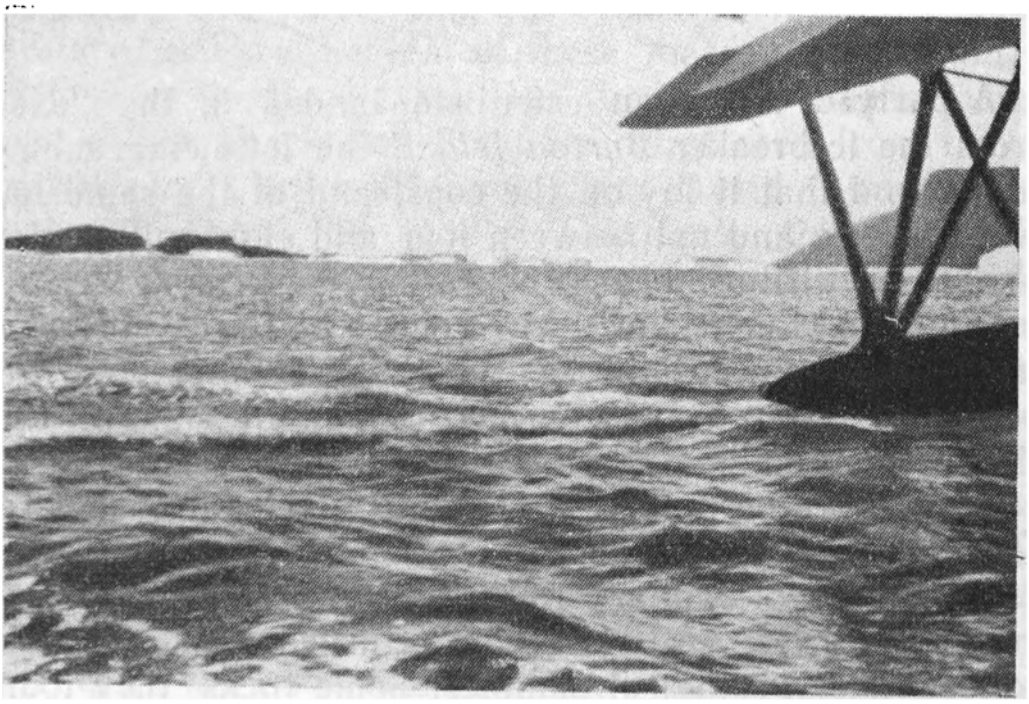
A bird's-eye view of the Bunger Oasis

A party of American scientists landed in the "oasis" from the icebreaker *Burton Island* the following summer and found that it lay on the coast and at the same level with the sea and not between four and eight miles inland and at an altitude of 200 metres as erroneously reported before. The bigger lakes turned out to be fjords jutting out from under the coastal ice, while the smaller ones were bodies of water formed by melting ice. In some of them the water is saline, in others fresh. The scientists discovered moraine, left by a receding glacier probably several thousand years ago.

At the end of January 1956, the Bunger Oasis was surveyed by Soviet explorers, who returned with a valuable collection of geological samples. Some rocks, they found,

were covered with black, gray and white lichens, while along the channels of the streams there were various types of moss. In some of the sun-warmed lakes the temperature of the water was as high as 11° C. and Professor K. K. Markov of Moscow University even risked taking a dip in one of them.

Three ice-free spots were discovered by the Norwegians on Ingrid Christensen Coast in 1935-37. Stretching from southwest to northeast, they are 14, 11 and 40 miles long respectively. The last "oasis," lying in 78°E., borders in the south on the Westfahl Plateau and is more than 250 square kilometres in size. Here and there in the hills are fresh-water lakes up to 6.5 kilometres long, some of them blue, others green and still others with rust-coloured stripes. It was here, too, that American flyers saw a lake that looked black from the air. There are large colonies of penguins and seal rookeries on the shores of the Westfahl Oasis.



Seaplane on one of the lakes of the Bunger Oasis, February 1947 (Byrd expedition)

Smaller "oases" were discovered by the 1946-47 Byrd expedition on the coast of Victoria Land on the same parallel with McMurdo Sound (the Prince Albert Mountains and Britannia Range). Here, too, there were blue and green lakes, but all of them ice-bound. The "oases" lay in valleys surrounded by rocky mountains and glaciers. Some of the snow-free patches were 10 miles long and covered, as far as it could be gauged from the air, with moraine. Byrd pointed out that these valleys were very much like the ice-free territory discovered by the Scott expedition off the Ross Sea.

No traces of volcanic activity or underground springs were found in any of the "oases" which, explorers say, were formed as a result of the recession of glaciers, deglacierization of elevations on the coast and denudation by wind action. In these conditions solar heat accumulating on the dark surface of the hills during the polar summer is sufficient for the existence of the "oases." Soviet observations in the Bunger Oasis in 1956 showed that because of the winds there was no solid snow mantle there even in winter.

There are also other oases. One of them was discovered by the Scott expedition of 1901-04 near McMurdo Sound[1] and lies in the channel of a receded glacier. The mountains surrounding this seven-mile-long and two-mile-wide oasis are covered with snow. At the edge of the glacier in the valley is an egg-shaped lake. The oasis is lifeless: there are no traces of vegetation or plant fossils. The bottom of the valley is covered with black boulders up to four metres in diameter and other morainal deposits. A streamlet flows in summer from under the sheer wall of the glacier deep inside the valley.

Another oasis was discovered by the Byrd expedition in 1941 on Lagotellery Island off Graham Land. Approximately, 4,000 square kilometres in area, it lies at the bottom

[1] The so-called Dry Valley.

of a valley surrounded by ice and is completely covered with a green blanket of mosses and lichens. In some places the former are very dense and form little swamps. The Americans also discovered grass and one flowering plant. There is nothing mysterious about the origin of this oasis, for it is known that there are hot springs in Graham Land. On Deception Island one can stand on snow and boil eggs in such springs. The temperature of the water is 88° C.

A somewhat original oasis is the horseshoe-shaped gulf on whose shore the Australians have set up their Mawson Base (67°36′S., 62°53′E.—Queen Maud Land). The shores of the gulf, sloping amphitheatrically towards the sea, are covered with boulders and brightly coloured with mosses and lichens—there are twelve different types of the latter. To the west and east stretches shelf-ice.

There are rocky elevations covered with mosses and lichens in other coastal areas, most of them in the northern part of Graham Land. More than twenty islets, partially or wholly free of ice, lie around the James Ross, Vega and Snow-Hill islands (from 63°30′S. to 67°S.). One of them, in lat. 60°39′S. and long. 57°28′W., is about four miles in diameter and its plateau, rising 457 metres, is free of snow. There is no snow either on the 300-metre-high plateau of Carlson Island two miles northwest of James Ross Island. Also free of ice and snow are the 3.5 mile-long northeastern prominence of Snow-Hill Island, Cape Hamilton on James Ross Island and several other places in this region. There is, moreover, an oasis archipelago in the Indian Ocean sector (109°E.)—the Grierson Islands, now the site of the U.S. Wilkes Station.

In conclusion it should be pointed out that in 1939 a German expedition aboard the *Schwabenland* carried out air reconnaissance over Queen Maud Land and discovered a number of ice-free lakes in the region between 2°E.-8°W. and 73°30′-74°S. Some of the data collected by the expedition were not made public. Scholes writes that the British Admiralty decided to survey them after the war

and sent specialists to Germany where they found materials saying that the Germans had found a "warm region" of 105,000 square kilometres, that is, bigger than Tasmania, in the above-mentioned area (J. Machowski, *Antarktyka*, Warszawa, 1953). However, the Norwegian-British-Swedish expedition of 1949-52 failed to find this oasis. The "lakes" turned out to be patches of blue glacial ice denuded of snow.

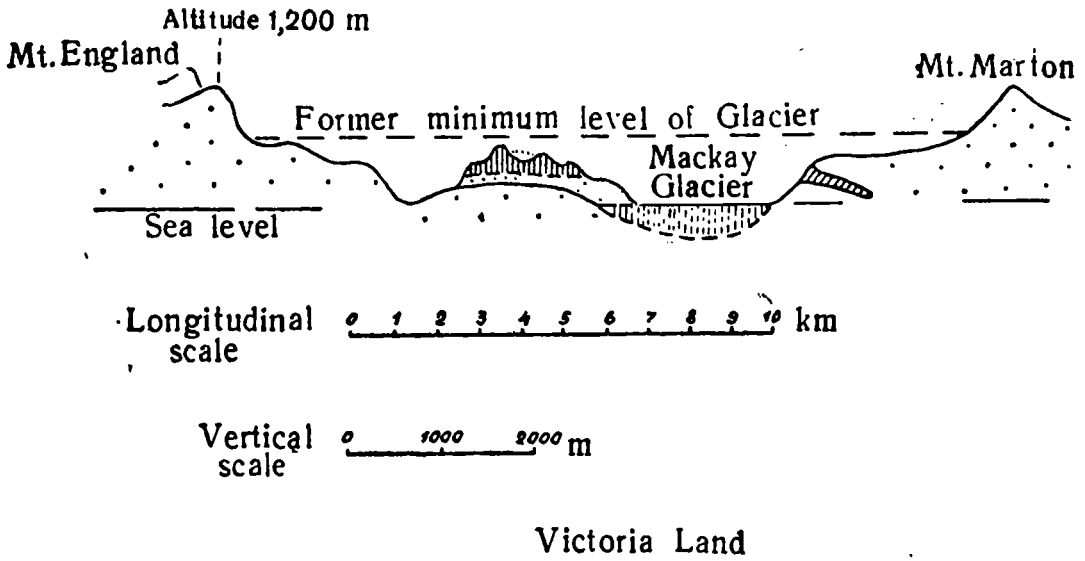
And, finally, to the oases we have mentioned above we may add the snow-free mountains, lakes and streams discovered and surveyed by the British expeditions of 1934-37 and 1948-49 on the shores of King George VI Strait in 70°-71°S.

DE-GLACIERIZATION

The recession of Antarctica's marginal ice was first observed more than half a century ago by Borchgrevink (1899), who noted that the edge of the Ross Barrier had receded 25-35 kilometres southward since 1841. This was later confirmed by Scott. Analyzing the glaciation process in Graham Land, the Swedish expedition under Nordenskjöld (1901-03) established that the thickness of the continental ice-sheet there had decreased by about 300 metres. In 1939-41, the eastern party of Byrd's expedition recorded rapid recession of continental glaciers in Graham Land. De-glacierization in Antarctica was reported also by the German expedition headed by Drygalski in 1901-03: on the basis of a survey of glacial deposits the German explorers computed that the ice mantle in Kaiser Wilhelm II Land had grown 350 metres thicker. Wright and Pristley hold that the Ross Barrier used to be 270 metres thicker and stretched 350 kilometres farther north. Traces of higher altitudes have been discovered also in Queen Maud Land and Victoria Land. Further evidence of ice recession are the oases.

In some cases, the causes of the recession of continental ice are purely local. For instance, orography and wind ac-

tion in certain parts are conducive to the denudation of the land surface and formation of oases. In other places, the cause of recession may be lesser precipitation and this is the reason suggested in the case of the Ross Barrier. The Ronne expedition established that the Lassiter (Filchner) Shelf-Ice had receded approximately 100 kilometres to the south of 40°W. from 1912 to 1947, while the northern edge of the shelf-ice in King George VI Sound receded 65 kilometres to the south between 1940 and 1947.



Section showing maximum level of the Antarctic ice-sheet (after R. Fairbridge, 1952)

Odell writes that recession in recent years is characterized by the calving of huge tabular icebergs (up to 150 kilometres in extent) and their drifting into the Weddell Sea. He compares the rapid recession of the Lassiter Shelf-Ice with the de-glacierization of mountainous regions in Coats Land and suggests that these two phenomena are influenced by climatic factors (*The Antarctic Today*, p. 46). In 1954, the present author observed the accumulation—a big one for these parts—of icebergs of shelf-ice origin off the South Shetland Islands. Some of them were many kilometres long, others were cut up by vertical crevasses

into numerous tabular formations. Within a few days we saw more than 1,000 icebergs of shelf-ice origin.

A year later, the author witnessed another phenomenon, which also may be linked with the intense disintegration of the shelf-ice: a tabular berg rising 100 metres above the water off Joinville Island. This was unusual because, as a rule, tabular bergs are between 12 and 40 metres high and very rarely higher.

We have already spoken of the 50-mile recession of the Bellingshausen Shelf-Ice, which is located in 16°E.

In 1931, a Norwegian expedition aboard the vessel *Norvegia* charted the shelf-ice projecting from Princess Astrid Land to 68°30′S. (between 5 and 10°E.). And in the same spot the 1938-39 German expedition aboard the *Schwabenland* found an open sea with depths ranging from 1,500 to 2,500 metres. The edge of the shelf-ice had receded over 180 kilometres.

On January 30, 1774, sailing in the *Resolution* in 71°10′S., 106°54′W., Cook saw an ice wall which he described as a gigantic fragment of continental ice that had broken off and was drifting out to sea. The distance to the Antarctic coast (151 miles) was shorter than the longest of the known Antarctic icebergs (208 miles).

"At four o'clock in the morning," Cook wrote, "we perceived the clouds, over the horizon to the south, to be of an unusual snow-white brightness, which we knew denounced our approach to field ice. Soon after it was seen from the top masthead.... It extended east and west, far beyond the reach of our sight....

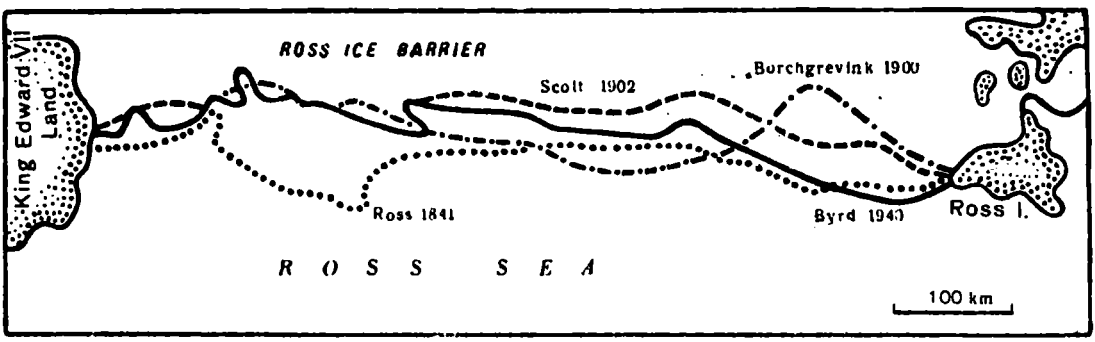
"Ninety-seven ice hills were distinctly seen within the field, besides those on the outside; many of them very large, and looking like a ridge of mountains, rising one above another till they were lost in the clouds. The outer or northern edge of this immense field was composed of loose or broken ice close-packed together, so that it was not possible for anything to enter it.

"This was about a mile broad; within which was solid

ice in one continued compact body. It was rather low and flat (except the hills) but seemed to increase in height as you traced it to the south" (*A Voyage Towards the South Pole and Round the World,* p. 208).

But while some glaciers are receding, others are growing in size. Ronne's air reconnaissance in the Weddell Sea in 1947 showed that, like the Filchner Shelf-Ice, the Larsen Shelf-Ice had moved slightly into the sea. In 68°S. its edge was up to 18 kilometres farther to the east than it had been in 1893.

From 1902 to 1911 the Ross Barrier had moved up to 18 kilometres north in some places, and another 22 kilo-



Position of the Ross Barrier in various years (H. P. Kosack, 1954)

metres from 1911 to 1935. On the whole, however, the trend lately has been towards recession.

Some explorers have lately claimed that the recession of glaciers is due to the fact that Antarctica's climate is growing warmer. Interesting details on climatic changes in the Ross Sea are given by Buinitsky: the mean temperature in the Bay of Whales in 1911 was minus 25.8°C., in 1929—minus 24.9° and in 1940—minus 23.7°. The temperature in the Southern Hemisphere increased more during the winter months than in the summer. In August, for instance, the increase was 8.5° (*Antarctica,* p. 42). It should be borne in mind, however, that the Ross Barrier did not recede all this time, but advanced northward.

Observations by the Norwegian-British-Swedish expedition in Queen Maud Land showed that the change in the climate in this part of Antarctica had not been uniform in the past decades.

Judging by the thickness of the layers of melted ice in the shafts sunk in the Maudheim Glacier, the summer months of 1944-45, 1946-47, 1947-48 and 1949-50 were warm with considerable thaws; in 1936-37, 1937-38, 1939-40 and 1948-49 they were normally cold; and in 1934-35, 1935-36, 1938-39, 1945-46, 1950-51 and 1951-52—unusually cold.

Denudation in some parts of Antarctica and the recorded increase in temperature in certain regions take place simultaneously with a similar process in the Arctic. But while there is no doubt that the change in the temperature of the air is responsible for denudation, it would be wrong to attribute it solely to this growing warmth. Valter Schytt, who took part in the Maudheim surveys, wrote in 1954 that the change in the temperature of the air in Antarctica influenced the dynamics of glaciers differently from the way it did in the northern regions where, as it is known, deglacierization is speeded up by the rise in temperature In Antarctica, he concludes, higher temperature and an increase in atmospheric circulation would intensify glacierization, since they would lead to greater precipitation of snow: a rise in temperature even by 10°C. would cause greater ablation only in the coastal regions.

There is yet another important factor one should remember when analyzing the laws governing the recession of Antarctic ice barriers and that is that often their unexpected and rapid recession is brought about by the intense breaking off of icebergs and is thus not attributable to climatic changes. Most of the barriers are afloat and their displacement south or north is determined by the interaction of two factors: the speed with which ice spreads northward and the intensity with which icebergs calve. The changes in the former depend on the increase in the thickness of

the entire shelf-ice (precipitation minus surface ablation and underwater erosion) and, to a lesser degree, on the intensity with which it is nourished by glaciers. Local changes in the speed may also result from changes in the surface relief of the barrier.

In analyzing the effect climatic changes have on the position of a barrier, many assume that the intensity with which bergs break off remains unchanged. Actually, however, this breaking off may be caused by impulses, involving large fragments in some years.[1] Wright and Pristley, for instance, attributed the difference in the positions of the Ross Barrier in 1841 and 1899 to earthquake action which had caused cracks in the shelf-ice.[2] This too was the cause, they say, of the vast accumulation of icebergs which Shackleton saw in 1908.

Another explanation for the impulsive character of the calving of icebergs was given by the American Antarctic expedition in 1956. The Ross Barrier on the same longitude with the Little America Station moved ten miles north between 1902 and 1948. In 1955, the Barrier receded ten miles to the south. Surveys revealed that the calving of ice on a 120-mile stretch west of the Bay of Whales occurred almost on a straight line, probably along a crack.[3] American explorers presume that the breaking off occurs periodically when the equilibrium of the barrier, which depends on its contours and tempo of movement, is disturbed.

The calved iceberg was found on November 17, 1956, by the icebreaker *Glacier* 150 miles west of Scott Island. It turned out to be bigger than originally presumed: 208 miles long and 60 miles wide.[4]

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[1] "The eruption of icebergs," according to Prof. Zubov (1956).

[2] Zubov draws attention to the indirect role earthquakes play in the disintegration of barriers—the formation of marine seismic waves.

[3] *New York Times*, December 22, 1955.

[4] *New York Times*, November 19, 1956.

In the Pleistocene, during the formation of continental ice in Northern Europe and North America, the ice-sheet in the Southern Hemisphere spread to the continental shelf of Antarctica. Other ice-sheets covered Patagonia, the southern part of Chile and, possibly, New Zealand.

According to geologists, glacial activity in the Southern Hemisphere dates back to the Quaternary epoch. But, as we have already said, there is little unanimity on questions pertaining to the little-known Antarctic. Nordenskjöld, for instance, considered that the glacial epoch in Graham Land began several million years earlier than in the Northern Hemisphere. Pristley (1922) analyzed volcanics on Cape Adare and came to the conclusion that glacierization dated back to the mid-Tertiary. Fairbridge is more cautious about his conclusions. Proceeding from a comprehensive analysis of geological data, he writes that in Antarctica "so far no really satisfactory evidence of a glacial climate has been found in the region for any period earlier than the Quaternary."

Odell quotes Fuchs, a participant in recent British surveys in Graham Land, as saying that it is possible to determine the period of glacierization by establishing the age of the organic materials which went into forming the continental ice-sheet. Such materials are found when shelf-ice breaks and originate from places inhabited by birds and other live beings in the days when glaciers were less developed.

Determination of the morainal deposits north of the Ross Barrier by radioactive methods (Hough, 1950) revealed the simultaneity of glacial action in the Quaternary epoch (right up to a few thousand years ago) in both the Southern and the Northern hemispheres.

In the interglacial epochs, when Antarctica's climate possibly was drier, the mountainous regions could free themselves of ice and form lake-dotted "oases" like the ones discovered by the Byrd expedition in Queen Mary Land in 1947.

The causes of these age-old climatic fluctuations have not yet been fully studied. In fact, there are more than thirty hypotheses, each explaining the glacial epoch differently. Most of them, however, proceed from data pertaining to the Northern Hemisphere. Especially widespread is the hypothesis seeking to attribute glacial variations to Gulf Stream activity.

Nansen once wrote that the decrease in the depth of submarine ridges between the Atlantic and Arctic oceans could bring about a big fall in temperature in Scandinavia and vice versa (N. Zubov, *Antarctic Ice*, Moscow, 1945, p. 338).

Notwithstanding the similar astronomic causes of glacierization, climatic changes due to regional factors are bound to lead to different glacial developments in different regions (K. K. Markov, *Paleogeography*, Moscow, 1956).

Paleoclimatologists who have been latterly showered with data on south polar meteorology will agree with what Kidson said on the subject way back in 1937. Meteorologists studying weather in the Southern Hemisphere, the eminent scholar then said, could not but note how much meteorological thought and meteorological literature were influenced by the specific conditions obtaining in the Atlantic Ocean, especially by the stream of air and water known as Gulf Stream. This stream, Kidson added, exerted dominant influence not only on meteorological phenomena, but on meteorological thought as well (E. Kidson, *Meteorology,* Undated).

We shall return to glacial hypotheses in the chapter dealing with paleogeography. Here we shall confine ourselves to the statement that whatever may be the cause of the formation or ablation of the continental ice-sheet, the changes in its volume result in the withdrawal from or return into circulation of vast masses of fresh water. The area of the Antarctic ice-sheet is 25 times smaller than

the area of the Pacific and the decrease in the thickness of the sheet by 30 metres will raise the level of the Pacific by about one metre (since the area of the ocean will increase along with its level).

Early this century T. W. E. David wrote that if the ice-sheet of the continent, then believed to be 550 metres thick, were to melt, the level of the world ocean would rise by 15 metres. Today, we are in a position to correct this computation: it would rise by at least three times as much.

SEA-ICE

ICEBERGS

While the study of the paleogeography of recent glacial activity is of utter importance for compiling long-term synoptic charts for the whole of the world, the study of icebergs—though a problem of lesser scope—is just as important for practical activity.

Icebergs constitute the most notable peculiarity of the Antarctic waters and the Southern Ocean, as the ocean belt girdling Antarctica is known, may well be called an ocean of icebergs.

In the Antarctic one comes across icebergs all through the year—there are vast, dense accumulations of blue Venices with hundreds of palaces, there are icebergs enclaved within packed ice and individual icebergs floating in the ocean.

The northern boundary of the iceberg belt closely follows the tortuous line of the Antarctic Convergence, the boundary of the Antarctic waters. Like the convergence itself, the boundary of the icebergs extends farthest north in the Atlantic Ocean sector (in 48-50°S.), then in the Indian Ocean (in 50°S.). Its southernmost point is in the Pacific Ocean (in 52-58°S.), at various longitudes.

Seasonal variations in the boundary in the Atlantic is about seven degrees (from 44°S. in November-December to 51°S. in May-June), three degrees in the Indian Ocean (from 50°S. in November-December to 53°S. in May-June)

and about four degrees in the Pacific Ocean (from 53°S. in November-December to 57°S. in May-June).

It may thus be said that icebergs do not move north together with sea-ice, which does so mostly in August and September, but later, this probably being due to the fact that their movement is impeded by the ice pack. Antarctic icebergs disintegrate more slowly and recede to the south later, by a month or two, than pack-ice. Moreover, as we have already seen, their boundary recedes very little and never farther south than the 50th degree. The farthest icebergs recede north, barring possible deviations, is to the 30th degree in the Atlantic, and to the 40th degree and beyond in the Pacific. For that reason there is always the danger of a ship meeting a berg in the Antarctic. There have also been cases of Antarctic icebergs being carried by the waves to the tropical borderline. In 1894, for instance, a fragment of an iceberg was seen in the Atlantic in 26°S.

The unusual dimensions of Antarctic bergs permit them to reach warm latitudes. South polar literature says that the biggest known iceberg was 518 metres high. This figure, however, is challenged, for its draught then would have been between 1,000 and 3,000 metres, depending on its form, and at no place in the Antarctic, not even in the centre of the continent, has the ice-sheet been known to be so thick. Neither has any coastal glacier been known to be between 1,000 and 1,500 metres thick. Most of the Antarctic bergs are much lower than the one mentioned above. Tabular bergs are usually between 12 and 40 metres high, and the tilting and disintegrating bergs—between 20 and 50 metres high.

The length is usually between 100 and 400 metres, though some of the tabular bergs observed in the Antarctic waters were from 100 to 150 kilometres long.[1] In recent

[1] Before 1956, the biggest Antarctic iceberg was the one encountered by the Norwegian whaler *Odd I* on January 7, 1927, off Clarence Island. It was 170 kilometres long and rose 40 metres above the water.

years icebergs of this size have calved from the Lassiter Shelf-Ice and because of that it is expected that it will undergo considerable changes in form.

If an iceberg of such length were to tilt only 10′ as a result of uneven melting, its height and draught would increase by almost 450 metres.

However, huge fields of bergs break up rapidly under pressure caused by changes in temperature, uneven melting and wave action.

An interesting result of this phenomenon is the accumulation in the Antarctic of masses of homogeneous tabular bergs one encounters far from the shores of the continent. As a rule they bear no traces of disintegration. Sir Ernest Shackleton appears to have been the first explorer to describe this mysterious accumulation of bergs. It was on January 16, 1908, in lat. 68°6′S., long. 179°21′E., some 660 miles north of the Ross Barrier and 50 miles southwest of the tiny Scott Island, that Shackleton saw an accumulation of thousands of tabular bergs through which his ship plied for 80 miles in a southerly direction. Eastward, he wrote, the field extended beyond sight and the bergs were so close to one another that the vessel could not get through to enable him "to make closer acquaintance with them."

"The vast majority of the bergs we passed," the eminent British explorer went on, "were not more than 130 feet high and seemed to be of a fairly uniform thickness."

In Shackleton's opinion, these bergs had calved from the ice barrier, for there were absolutely no traces of rock sediments or any other signs of their being of continental origin. And the most interesting feature was not the number of the bergs, but the total absence of any signs of disintegration. "Of one thing I am certain," he wrote. "This ice had not long left the parent barrier or coastline, for there was no sign of weathering or wind action on the sides; and if they had been afloat for even a short period they must infallibly have shown some traces of weathering as the soft snow was at least fifteen to twenty feet thick."

And the conclusion he drew was that, at "no great distance," there was some unknown ice barrier and consequently land. A later expedition, he said, might be able to work more to the east and solve the "riddle." But, as subsequent surveys showed, the land proved to be 310 miles away and the barrier 660.

Describing this unusual mass, Shackleton called it "snowy Venice," "unpeopled city," "White city," and the streaks of water between the bergs—"streets" and "lanes." There was no explanation then for the phenomenon he saw, it seems, and the expression "ice city" became a literary name for a large mass of bergs.

It was only in these past few years that explorers found the explanation for the presence of these undestroyed bergs. As we have already said above, in 1956 the American vessel *Glacier* came across an iceberg 208 miles long and 60 miles wide, in the same spot where Shackleton saw his bergs. This huge mass of ice had been driven there by the waves from the Ross Barrier. Observations made in 1954 by the ships of the Soviet *Slava* flotilla revealed that the drifting tabular bergs were apt to break into thousands of fragments to form the kind of "ice cities" seen by Shackleton.

In November 1954, cruising in the Scotia Sea off the South Sandwich Islands, the *Slava* expedition (the present author was one of its members) encountered a series of eleven "ice cities" in which the tabular bergs bore no traces of weathering, were of uniform height and length and of similar stratified structure. The size of the bergs varied from field to field, ranging from 7 to 20 metres in height and 30 to 100 metres in length.

Passing these "cities," the Soviet researchers registered 977 bergs. Thus, assuming that the fields were square in size the total number of bergs they contained must have been in the vicinity of 100,000.

Apart from the "ice cities," the explorers encountered vast flat-topped ice-floes some 20 metres high and 11 miles

long. Some had vertical cracks at regular intervals of 70 to 100 metres. From the looks of these cracks it was evident that these drifting fragments of land ice would soon break up into numerous little bergs of uniform height and length.

Most of the "cities" and ice-floes were about 10 metres high and were thickly covered with snow. In some cases, it was more than 7 metres thick (Shackleton gave the same figure). These may thus be classified as bergs of snow origin. Some of the bergs, however, were higher and were mostly of the shelf-ice type. A fact worth noting is that Shackleton's bergs were about 40 metres high, that is, twice as high as the biggest bergs we had come across.

According to Professor Zubov, the floes are broken into "cities" by swells. Another factor may be the uneven underwater thermal deformation.

By disregarding the degree of plastic deformation of ice one arrives at an extremely postulated evaluation of the significance of temperature variations.

Let us suppose that the horizontal dimensions of an iceberg are so much greater than its height that its flexion as a result of uneven thermal expansion is made impossible by the resistance of isostatic forces.

In this case, the floe will undergo thermal deformation remaining, as it were, in a rigid horizontal position.

Thus, as it freezes, the upper layer of ice cannot contract and at the same time avoid tearing apart at the expense of flexion. Its contraction in the horizontal position necessarily entails its disintegration along the cracks, which form at the time when thermal tensions overcome the temporary resistance of ice. An analogical picture will be observed during the heating of the upper layer, with the exception that the cracking process will be determined by the degree of the temporary resistance of ice to pressure.

Here one must bear in mind that the appearance of cracks is not due to the absolute rise or fall of the temperature of the layer, but to the difference between the change in the temperature of an individual layer and the change in the average temperature of the iceberg (if this difference is nil, the floe will expand or contract uniformly without breaking up).

The thermal tension of a plate is expressed by the following equation:

$$\sigma = \alpha\tau E (1 - \mu)^{-1}$$

where α is the coefficient of linear expansion, τ is the change of temperature, E is the modulus of elasticity, is Poisson's coefficient.

It follows from the equation that the decrease in the temperature of one of the layers of ice by 1-2° C., in comparison with the average temperature of the iceberg, results in tensions which are sufficient to exceed the limit of plasticity and cause cracks.

Thus, if $\tau = 2°$ C.; $\alpha = 0.000055$; E = 75,000 kg/cm²; $\mu = 0.36$, the increase in tension will be $\sigma = 12.9$ kg/cm². According to Weinberg, fresh-water ice disintegrates if the average tension exceeds 11.1 kg/cm².

Disintegration of a floe by wave action may be evaluated quite easily if we assume that the width of a floe does not influence the load necessary to cause it to crack.

Let us assume that the front of a tri-dimensional wave is parallel to the ice barrier and that the cross-section of the barrier with the surface of a ruffled sea forms a sinusoid. A similar sinusoid, though somewhat flatter, will be formed by the isobaric surface of the wave at the bottom of the submerged portion of the barrier. Hence the épure of the load on the submerged edge of the barrier will also be sinusoidal.

The maximal moment of flexion will be created along the verticals passing on the edge of the barrier through the crest and trough of a wave.

The conditions of disintegration may be determined by the equation:

$$\sigma h\pi^2 = 6a^2 \delta n e^{\frac{2\pi z}{L}}$$

where h is the height of the barrier,
a is the distance between the crests of waves,
δ is the density of water,
n is the height of the wave,
z is the draught of the barrier,
L is the length of the wave.

The actual thickness of a barrier, apart from pure ice, includes layers of snow and névé. In the equation we must substitute pure ice, equivalent to layers of snow and névé in resistance to flexion.

Calculations show that the tension created by a swell 10 metres high, 180 metres long and with a distance of 180 metres between the crests of waves, is sufficiently strong to cause cracks in a barrier

rising 15 to 18 metres above the surface (temporary resistance to flexion is taken to equal 16 kg/cm², the density of ice—0.8).

Since we presume that the width of a barrier does not influence disintegration, the results of the wave action will be somewhat exaggerated.

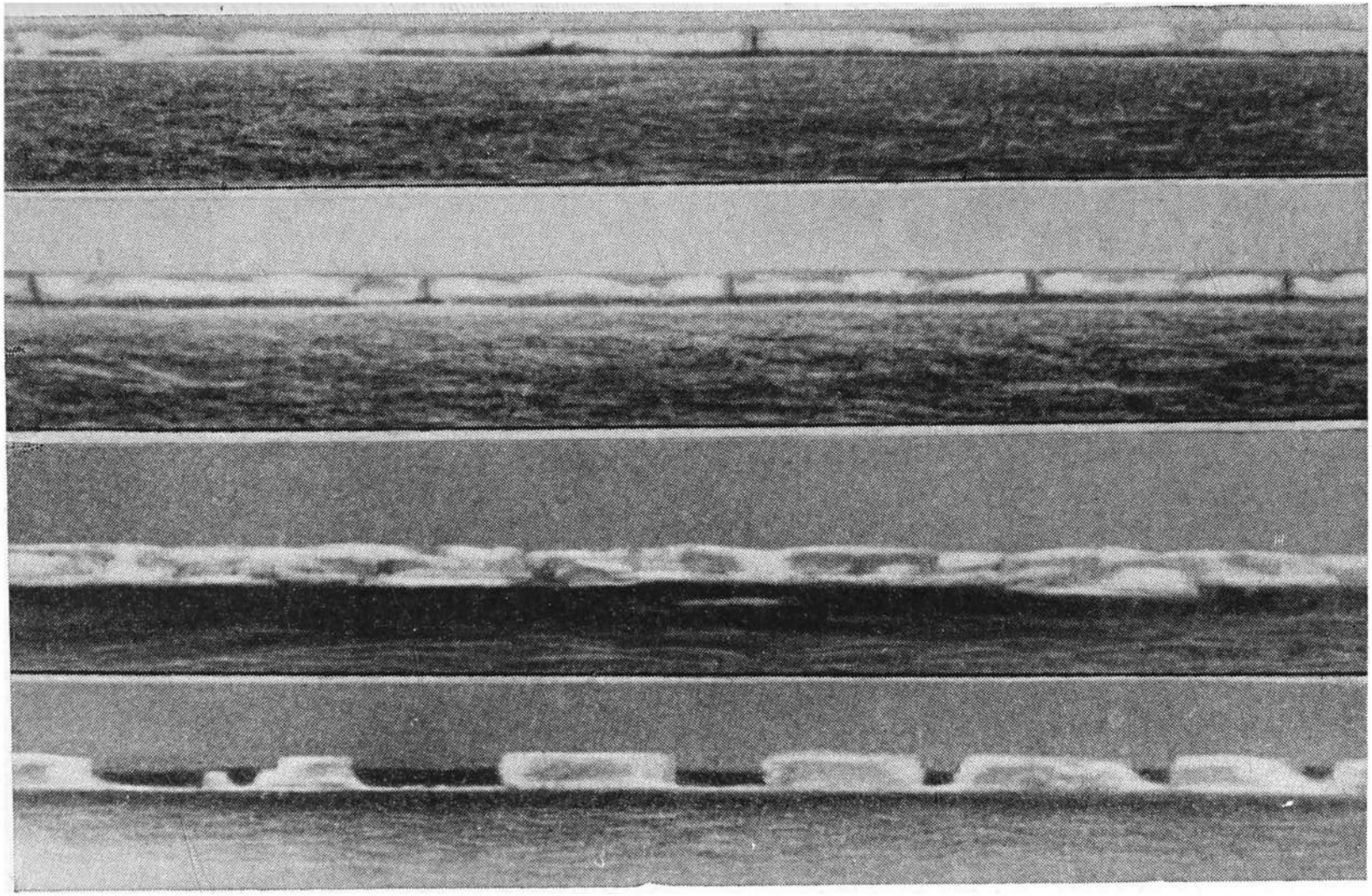
Erosion of a floe by wave action may be pictured as follows. A swell approaches an ice barrier and transforms into standing waves. Maximal tensions, created by contact between the barrier and the crests and troughs of waves, cause the barrier to crack vertically. These cracks are enlarged and deepened by new waves. The edge of the ice slab is cleaved and the clefts are further eroded by waves.

To distinguish land-ice floes which give birth to "ice cities" from ordinary tabular bergs we might call them *iceberg fields.*

"Ice cities" are always covered with mist and their mirror-like streets seem dead. We have never seen any penguins or other birds on them, but very often the foot of the edge is covered with microscopic green algae that look like mould.

Big accumulations of bergs are encountered in various parts of the Antarctic, presenting an impressive sight of unique beauty. T. R. Henry, who saw them in the Ross Sea, writes that they look like "a dead city on some other planet. Everywhere is absolute silence, the cumulative silence of a million years. The surface of the water surrounding the bergs is glass-smooth" (*The White Continent*, p. 146).

The calving of shelf bergs from barriers was observed in the Weddell Sea in February 1912 by the Filchner expedition. When the explorers landed on the shelf-ice, which now bears the name of the expedition's leader, it was covered with pack-ice. A blizzard on the following day swept pack-ice away and deprived the shelf-ice of the cover which protected it against wave action. A big swell from the northwest caused rapid disintegration of the 50-metre-high barrier. Some of the bergs breaking off from the barrier were almost 30 kilometres long and the party found them-



Disintegration of an iceberg field into tabular bergs. (Photographed by the author in Antarctica, in November 1954 off South Sandwich Islands.) The iceberg field is about 20 metres high.

selves floating on one of them (E.W. Hunter Christie, *The Antarctic Problem,* p. 193).

The above-mentioned instance shows that the integrity of the shelf-ice had been undermined by isostatic tensions before the appearance of the swell. It is these tensions, caused by the uneven melting process and accumulation, as well as the thermal influence of water and air, tides and swells which constitute the factors making for the disintegration of ice barriers into bergs.

The Ronne expedition discovered on the Lassiter Shelf-Ice, in 60°-58°W., a strip of cracks stretching parallel to the edge of the shelf-ice approximately 10 miles from the sea, possibly caused by tides (Finne Ronne, *Antarctic Conquest,* New York, 1949, p. 248). And the Byrd expedition doing survey work at Little America, observed the Ross Barrier repeatedly rise and subside during the lunar tides. These vacillations created a ramified network of crevasses which were concealed by snow and looked like minor deeps.[1]

Bergs sometimes calve from crevassed barriers absolutely unexpectedly for the observers. This happened to the Mawson expedition in 1912. Their ship was less than 300 metres from the Shackleton Shelf-Ice when an immense piece of ice suddenly and noisily broke off and disappeared under water. After a few moments it rose to the surface and eventually broke into a dozen small bergs (T. R. Henry, *The White Continent,* p. 168).

After calving from glaciers or ice shelves, the bergs usually drift northward, although many remain in the coastal waters and disintegrate without crossing the Antarctic Circle. These coastal bergs present the greatest menace to ships at anchorage. In 1947, four ships of the Byrd expedition were unloading on the Ross Barrier in the Bay of Whales when a berg floated into the passage be-

[1] The sea-level under the Ross Barrier in the Bay of Whales rises or subsides one metre and such vacillations, Dr. Poulter says, can create undulating curves in the barrier's plastic body (*The White Continent,* p. 156).

tween the ice walls of the bay, stopped short and locked them in "like a cork in a bottle," to quote one member of the expedition. After remaining motionless for 36 hours, it entered the bay and stopped next to the ships. Two days later it left through the entrance and drifted westward. The interesting thing is that it came to and went out of the Bay of Whales against the wind (*The White Continent*, p. 169).

Shelf bergs are the most numerous, although one encounters many glacier bergs which calve from the land ice descending from the interior of the continent. This ice projects ice-tongues for many kilometres seaward and they break off to form bergs. That is facilitated by the crevasses which often form as the glaciers descend the shore into the sea.

The disintegration of the ice-tongues which slope into the sea is influenced to a certain degree by the buoyancy of ice. Before it reaches the shoreline, the glacier under its own load presses close to the rock bottom. As the edge of the glacier enters the sea, the pressure of the load is reduced by the rising buoyancy. Equilibrium sets in some distance from the shore, the load in some section of the glacier being equal to buoyancy. With the glacier continuing its seaward movement and submerging, its buoyancy will increase until it causes flexion or the breaking off of its edge and the forming of a berg.

The picture will not change if, instead of the glacier descending, the sea-level will rise as a result of tides or wind action.

In computing the deformation and disintegration of the ice-tongues, we may apply the theories of plasticity and resistance of materials, assuming that ice reacts to pressure as a plastic or elastic body.

This last assumption is more valid in the case of fast-operating pressure—tides and wind action. As the author's computations have shown, the places where the glaciers break off and the length of the calving bergs may be found through the equations:

$$x = \sqrt[3]{\frac{2\sigma n^2}{q_w \sin \alpha}} \tag{1}$$

$$x^2 (q_w - q_i) \cdot \cos \alpha \, (1 + 2x_0 x^{-1}) = \sigma n \tag{2}$$

$$2x(q_w - q_i) \cdot n \cdot \cos \alpha - q_w (x - x_0)^2 \cdot \sin \alpha = 0 \tag{3}$$

where x is the length (in metres) of the calved berg,
q_w is the density of water in t/m³,
q_i is the density of ice,
α is the angle at which the ice-tongue slopes,
σ is the disintegrating pressure on flexion in t/m²,
n is the thickness of ice in metres,
x_0 is the length (in metres) of the part of the submerged ice-tongue.

The equations above presume that the ice-tongue disintegrates in the course of flexion, that it has a right-angled section, is homogeneous and free of crevasses. They do not take into consideration the action of inertia, wind, waves, tides, or the plasticity of ice.

Equation (1) permits to compute the disintegration of the glacier before its submergence, and equations (2) and (3)—after it. To find which glaciers will disintegrate before submergence and which will do so after, it is necessary to determine the conditions under which the glacier disintegrates at the moment of its submergence. These conditions are determined by the simultaneous solution of equations (2) and (3) with $x_0 = 0$.

$$\sigma = 4n(q_w - q_i)^3 \cos^3\alpha (q_w^2 \sin^2\alpha)^{-1} = k.$$

Hence, when $\sigma < k$, the glacier disintegrates before its submergence; when $\sigma > k$, after it.

With the density of ice equalling 0.9 t/m³ and the density of water —1.0 t/m³, the first condition is obtained, if

$$\sigma \leqslant 200 \text{ t/m}^2, \quad n \geqslant 500 \text{ m}, \quad \alpha \leqslant 5°40',$$

or

$$\sigma \leqslant 200 \text{ t/m}^2, \quad n \geqslant 100 \text{ m}, \quad \alpha \leqslant 2°50',$$

or

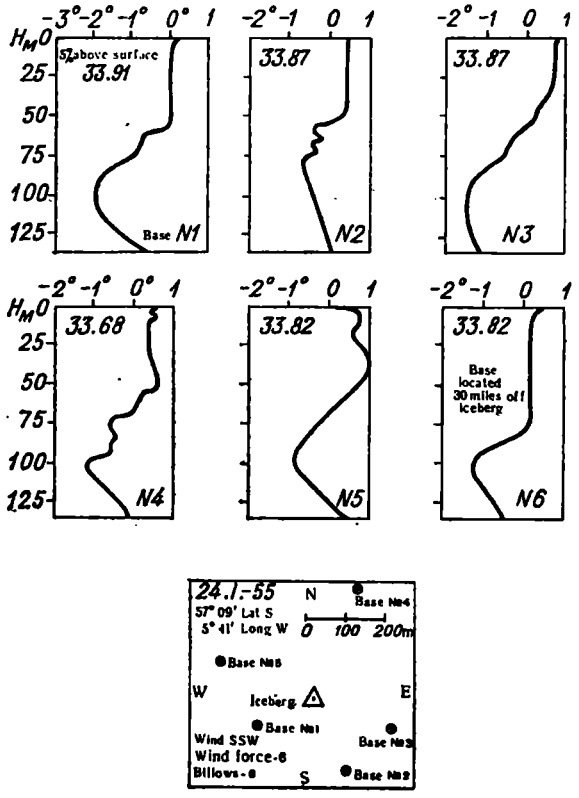
$$\sigma \leqslant 100 \text{ t/m}^2, \quad n \geqslant 100 \text{ m}, \quad \alpha \leqslant 4°.$$

Consequently, most of the glaciers calve before submergence. The greatest length of the bergs thus formed equals

$$2(q_w - q_i) n \operatorname{ctg} \alpha q_w^{-1} \text{ metres.}$$

The line of the disintegration of glaciers passes beyond the shore, although it is theoretically possible for glaciers whose edge is submerged to calve on the shore, provided $\alpha \geqslant 45°$, $\sigma \geqslant 200$ t/m², $n \leqslant 30$ m. In any case, the bergs thus formed are lower than the broken edges of the glaciers.

It should be borne in mind, however, that the computations above are based on a number of assumptions and are therefore approximate. The solution of the problem is of major significance for Antarctic study, for the greater part of the continent's coast is covered with glaciers.



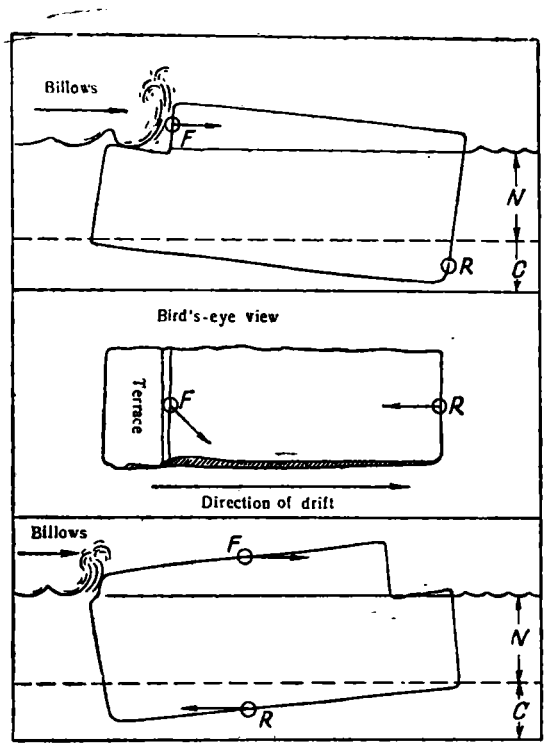
The temperature regime near an iceberg, as recorded by the author and I. F. Kirillov (after the *Slava* report to the International Whaling Convention)

Being extremely voluminous and submerging to depths of hundreds of fathoms, Antarctic bergs exert a considerable influence on the temperature and salinity of the Southern Ocean waters and the distribution of plankton. V. S. Nazarov, for instance, has calculated that the melting of the biggest iceberg encountered in the Antarctic until 1956 (a mass 170 kilometres long and rising 40 metres above the surface) gave about 1,800 cubic kilometres of fresh water, or seven times more than the Volga brings every year into the Caspian Sea. It has been observed that some species of whales are attracted to bergy regions, for there they not only find food and shelter from storms, but also rid themselves of certain skin parasites which cannot stand fresh water.

Many Antarctic birds, including penguins, choose bergs for their homes. We have seen bergs whose surface for hundreds of square metres was covered with droppings.

As the observations made by the *Slava* expedition of 1954-55 show, Antarctic bergs create a complex picture of surface and bottom water circulation and the attending vertical currents, caused by the thermal and dynamic interaction of the berg and various strata of water. The under-water part of a berg very often stretches to depths

of 100 to 200 metres and for that reason deep waters with high salinity and temperature and considerable content of biogenous elements—nitrates and phosphates—are drawn into circulation. The above-mentioned contradictory processes near icebergs create a complicated hydrological regime, characterized not only by de-freshening and freezing processes, but also by increases in temperature and salinity (see Fig. on p. 102).



Scheme showing the effect of elements on an iceberg in the wind drift
F—wind force, *R*—water resistance force, *N*—depth of the layer of water affected by tide, *C*—relatively stagnant water

Polar literature has time and again posed the question of using iceberg observations for determining currents. Bergs always drift sidewise with the tide (V. Buinitsky, *Antarctica*, p. 53). To this may be added some of the peculiarities observed in the movement of tabular bergs under the influence of the prevailing winds. The rear under-water part of the berg is eroded by wave action. As it emerges from the water, the front part submerges. The equilibrium is upset. As a result, the berg attempts to turn horizontally, moving with its raised part around the one submerged. Since the wind deviates to the right of the current, the turn will be counter-clockwise. After the berg has turned and its raised part moves ahead with the tide, the waves again begin eroding the part that is submerged. As erosion wears more of the submerged

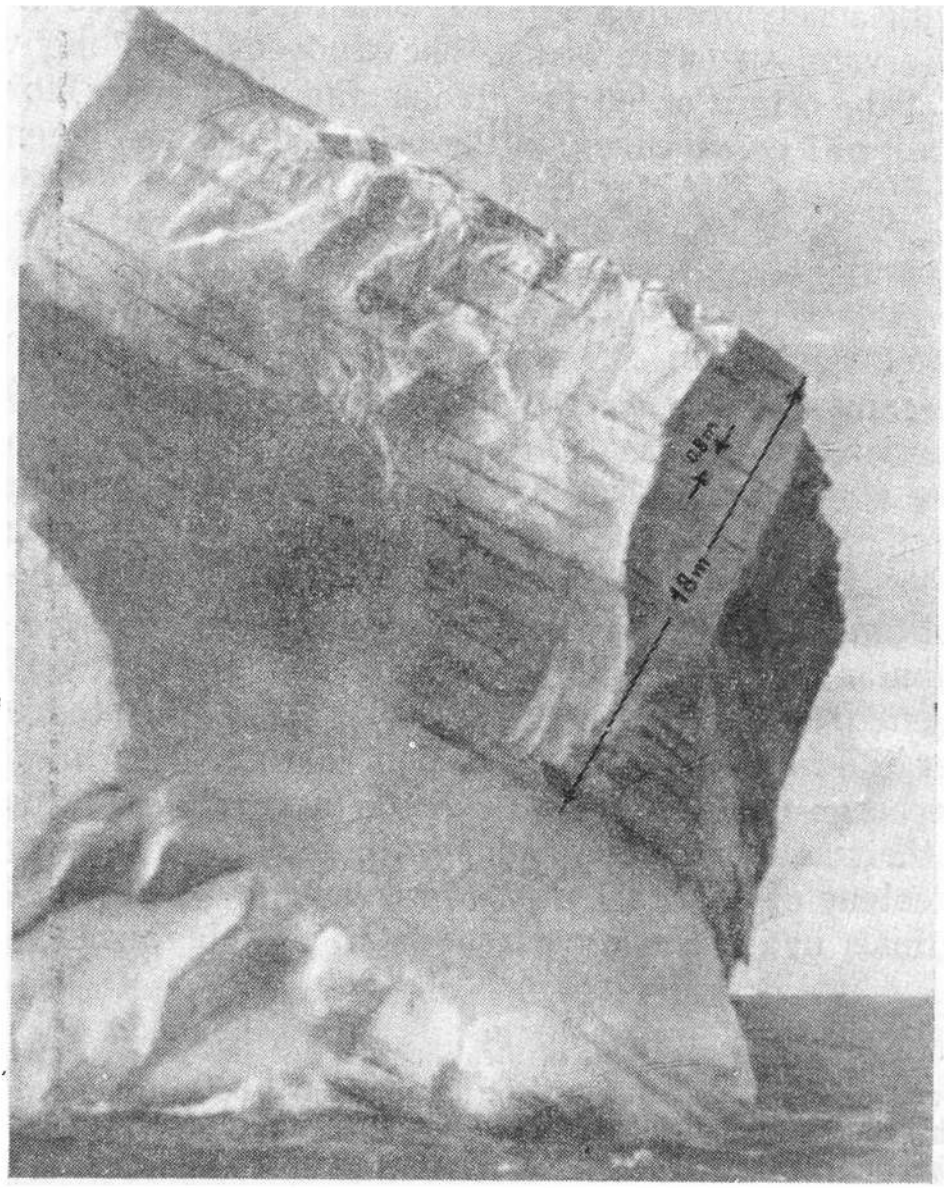
mass, the incline of the berg diminishes, then disappears and finally moves to the opposite side. After that, wind and the resistance of water will again turn the berg counter-clockwise with the raised part moving with the tide. The process can repeat itself several times (see Fig. on p. 103).

Icebergs are especially dangerous for ships blocked by ice, for, carried by the under-water currents in the opposite direction, they can smash the ice and crush the vessel. There are always heavy mists where the bergs accumulate and that makes navigation all the more perilous. The difficulties are felt most by the whaling ships which are often compelled to approach bergs in their pursuit of whales. There are cases on record of harpooned whales "tugging" the pursuing ship for hours on end.

As bergs disintegrate, there form big under-water promontories, or rams. Another danger for the ships is presented by the "tails" of the icebergs that break off in summer. Smoothed by the waves, they are usually deeply submerged in water and are difficult to discover by radar because they "hide" behind waves. As the measurements made by *Slava* reveal, these fragments are much more solid than sea-ice and are, therefore, very dangerous for navigation. Observations, carried on for two years, showed that in 90 cases out of 100 these fragments stretch leeward from the berg, and only with the recent change in the direction of the wind will they be windward of the berg.

Polar literature contains many unconfirmed hypotheses contradicting these observations. But even Bellingshausen, after sailing hundreds of miles past the Antarctic icebergs, wrote that fragments were encountered on the "lee-side" of almost every berg. These observations are necessary for ships sailing near bergs in poor visibility, at night, in mist or when it snows.

During whale-hunting many urgent operations—the mooring of tankers and whaling ships to the factory ship, repairs, etc.—are retarded by storm waves. Large bergs offer excellent natural shelter. Navigators, however, know



Stratified iceberg near the Larsen Shelf-Ice (photo by author)

very little about the drift and disintegration of bergs, their calving and overturning, and for that reason avoid approaching them.

Bergs are also important as orientators for finding killed whales that are left in water. In this connection the ques-

tion arises as to the speed and direction of the drift of the bergs.

When melting, fragments of icebergs sometimes cover up with a network of polygons, which are evidence of the large-crystal structure of ice. The study of ice along with that of the origin of bergs (glacier and shelf bergs, for instance) will reveal much on the origin and development of various forms of Antarctic land-ice.

CLASSIFICATION OF ANTARCTIC ICEBERGS

Tabular bergs of different structure and origin are the most common ice masses floating in the Antarctic. Those of barrier structure are white and that is due to the considerable air content. Stratification, particularly in the upper layers, is well defined.[1] The upper part of the berg may also be formed of névé several score metres thick.[2] The top is flat and the walls are vertical.

Tabular bergs of glacier origin are not infrequently white too as a result of weathering and disintegration under the impact of sun radiation. The manner in which these bergs disintegrate to a depth of several centimetres and their colour are very much different from the process and colour of barrier bergs. Moreover, one observes light blue hues in the fresh crevasses and protuberances of the

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[1] The clear-cut character of stratification depends on seasonal fluctuations in the temperature of the air and may be traced to various depths. Photographs taken by a German expedition in 1912 off the edge of the Filchner Barrier (78°S.) revealed almost ten layers of snow and névé. Off the Ross Barrier (near 78°S.), stratification has been traced to a depth of about seven metres, off the Maudheim Shelf-Ice (70°S.) to a depth of 12-18 metres and on bergs calving from the Larsen Shelf-Ice (65°S.) to a depth of more than 30 metres. Photographs taken by the present author in these parts show more than 60 layers of snow and ice in some bergs.

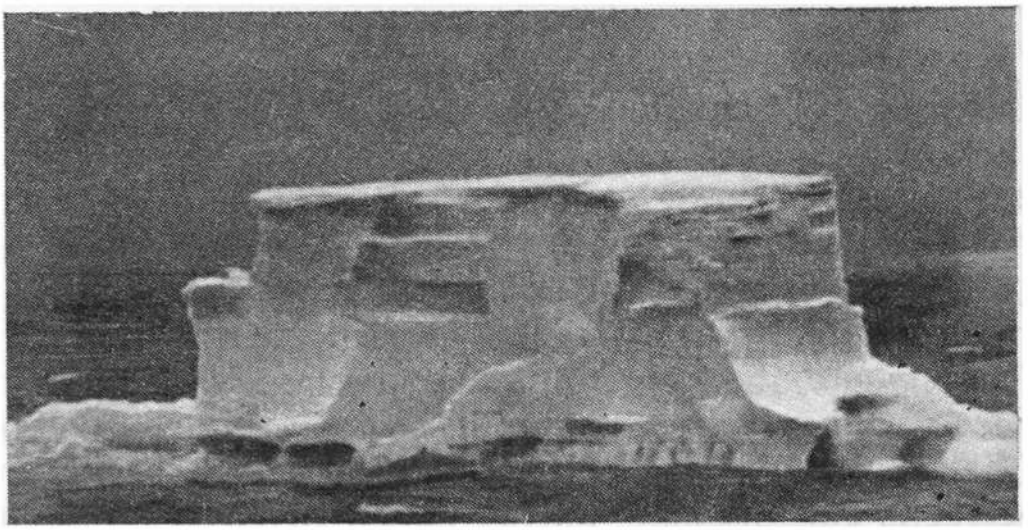
[2] In the "cold" zones of ice formation, the layer of névé is from 20 to 50 metres thick. (P. A. Shumsky. *Foundations of Structural Glaciology*, Moscow, 1955.)

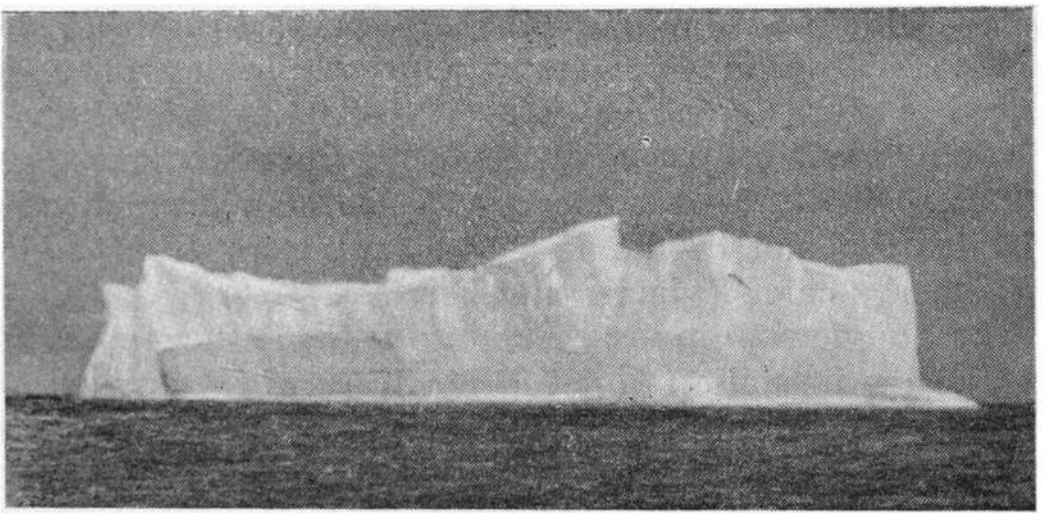
glacier bergs (sometimes the entire berg is light blue or blue). The surface and edges of these bergs are more rugged than those of barrier formations, they exist longer and their specific weight is greater. Very often glacier bergs contain rocks, sand and silt.

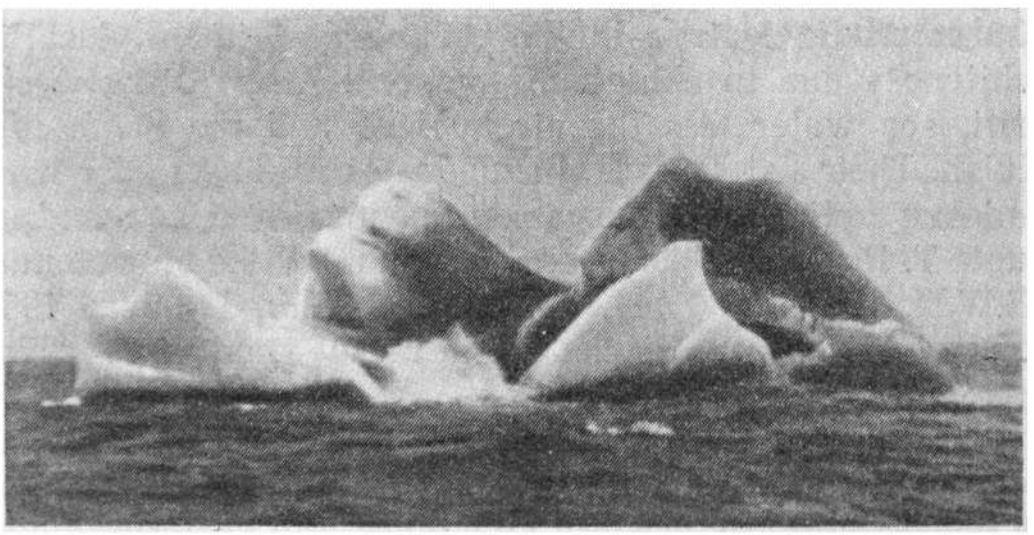
The names "glacier" and "barrier" derive from the places where the bergs form—ice-tongues and barriers. But, as we have already seen, in some cases the structure of barrier bergs is quite close to that of glacier bergs. The reverse is also possible: intense under-surface melting and accumulation of precipitated snow make the structure of land ice-tongues similar to that of shelf-ice. And because of that it is not always possible correctly to determine the origin of bergs. That is why classification of Antarctic bergs by their *origin* implies, strictly speaking, the present-day structure of the edges of mainland and barrier glaciers and not the names of the glaciers from which these bergs calve (glacier and barrier).

The unique conditions obtaining in the Antarctic region lead to the formation of yet a third type of tabular berg—the short-lived snowberg—off the continent and the islands, in spots where precipitation is heavy and great quantities of snow are wind-driven from the shore. Snowbergs form when snow-covered land-fast ice calves. Their characteristic feature in the early phase is the dazzling whiteness due to a high air content. After a few weeks' drift, sea water fills the air bubbles and the bergs turn bluish. Their flat surface disintegrates rapidly under wave and sun action. The bergs assume quaint forms and, to quote T. R. Henry, "float through the mist like blue clouds" (E.W.H. Christie. *The Antarctic Problem*, London, 1951, p. 173). The Americans call these snowbergs "blue spectres."

One also comes across black-and-white-dotted bergs that look as if they are camouflaged. A rounded berg about 15 metres high, its western side black and eastern—white, was encountered in 59°S., 11°W., towards the end of March







Snow iceberg. Height—8 metres. Dented glacier berg. Height—87 metres. Dark-green iceberg. Height—26 metres (photographed by author)

1955. The interesting thing was that these two colours were sharply delineated, without there being any semitones. British scientists call them "black-white" bergs. The dark spots are morainal intrusions, sometimes black and sometimes brown.

A disintegrating iceberg with a 25-square-metre brown spot of moraine was encountered in 54°S., 5°W., in December 1954, and another berg with a brown spot between 80 and 100 square metres in size was observed in 62°S., 16°W. in the following March.

The name "black-white" is quite the proper one, for from a distance there is a sharp distinct cut-off line between the two colours and the bergs really look black and white.

It is generally assumed that the black-white icebergs are irregularly pyramidal. That is so in many cases, but not always. Thus, in March 1955, in 62°S., 18°W., explorers met a tabular berg with broad vertical stretches of morainal intrusion from the top to the water surface, while in 62°S., 15°W., they came across a tilting tabular berg on whose outer wall was a morainal spot stretching 10 metres from the surface. Some ice-covered intrusions make icebergs look dark green, very original, and from afar they look like mountains covered with green mosses.

These characteristics are reflected to a considerable degree in the sailing directions for Antarctica worked out by the Scott Polar Research Institute and Discovery Committee. These directions refer to five types of bergs: tabular—flat, or stratified, bergs of barrier origin, called in British and American polar literature "barrier bergs"; glacier—less smooth than tabular bergs, also called "blue bergs"; névé; weathered; and black and white, which include morainic and bottle-green bergs.

The American sailing directions mention "unconformity bergs" whose barrier and glacier structures are clearly discernible. The lower part consists of monolithic blue ice rounded by wave action, and the top of névé layers. According to American authorities, unconformity bergs often

have silt bands and crevasses and calve from glaciers going through the transition stage from glacier to barrier structure. It is quite possible, however, that this unconformity is due to wave-action disintegration.

The American directions further speak of "ice island bergs" with dome-like surfaces, originating from smooth, thawing ice-tongues jutting out from barriers into the sea (*Sailing Direction for Antarctica*, Washington, 1942).

In the black-and-white category the Americans include "green bergs" (morainic) and "bandel bergs" (with silt bands on the surface).

The classifications above are based on the works of the British explorers C.S. Wright and R.E. Pristley, J. M. Wordie and P. Kemp, and other researchers. The positive value of these classifications and the results of the investigations made by the *Slava* permit classification of bergs as follows.

Types of Bergs (by Origin)

1) Snow, or land-fast, bergs form by calving and are covered with a layer of snow many feet deep. Since the maximum thickness of snow accumulation is never above seven metres, the height of these bergs does not exceed 14 metres, for otherwise the underwater part would be one predominantly of névé (see Fig. on p. 108).

Young icebergs are white, flat-topped, with well-defined layers. The density of the part above water is about 0.5 g. per 1 cm^3.

2) Névé, or barrier (stratified), bergs derive from glaciers whose seaward edges are of barrier structure. At least 20 metres of the part above the water surface is snow and névé or ice with névé layers. Horizontal stratification is clearly discernible. Young bergs are white, usually flat-topped. Névé bergs, as a rule, disintegrate by crumbling. The density of the part above water is 0.6-0.7 g/cm^3.

3) Monolithic, or glacier (blue), bergs calve from gla-

ciers whose seaward edges are of glacier structure. They are formed of glacier ice. The characteristic features are the bluish tones in the breaks, and sharp angles. The density of the part above water is 0.8-0.9 g/cm^3.

4) Black and white, or morainic, icebergs with relatively considerable amount of detrital material from the continent. The dark and sharply defined morainal spots on the surface are generally several square metres in size, and are sometimes mistaken by navigators for grounded boats, seals, etc. These bergs form in places where the glaciers amass a huge amount of moraine.

5) Dark green bergs whose ice apparently contains fine-rock particles which, while preserving the transparence of ice, give the bergs a dark green colouring that makes them look like moss-covered cliffs. The origin of these bergs has not been fully determined, since no samples of their ice have been obtained so far. It is quite possible, however, that it is connected with the accumulation of volcanic ash and various weathering products on the surface of the ice.

Forms of Icebergs

Original Forms

Floes—bergs with a horizontally flat top and length greatly exceeding the height of the above-water part (usually from a few to several dozen metres high and a few kilometres to several dozen kilometres long). Formed of snow or barrier ice.

Floes and tabular icebergs are of the same height, but not length. By floes we mean bergs of at least one kilometre in length.

Tabular bergs have a horizontally flat top and almost vertical walls of barrier, land-ice or snow origin.

Hummocky and *dented icebergs* are of irregular form with hummocky or dented surface. Glacier, morainal and dark green icebergs are usually of land-ice origin. Barrier

bergs sometimes also have an indistinctly outlined hummocky surface. The pyramidal form of the hummocky berg is not typical of the Antarctic (though it does occur in the case of the not-too-numerous morainic and dark green bergs). As a rule Antarctic bergs become pyramidal as a result of disintegration.

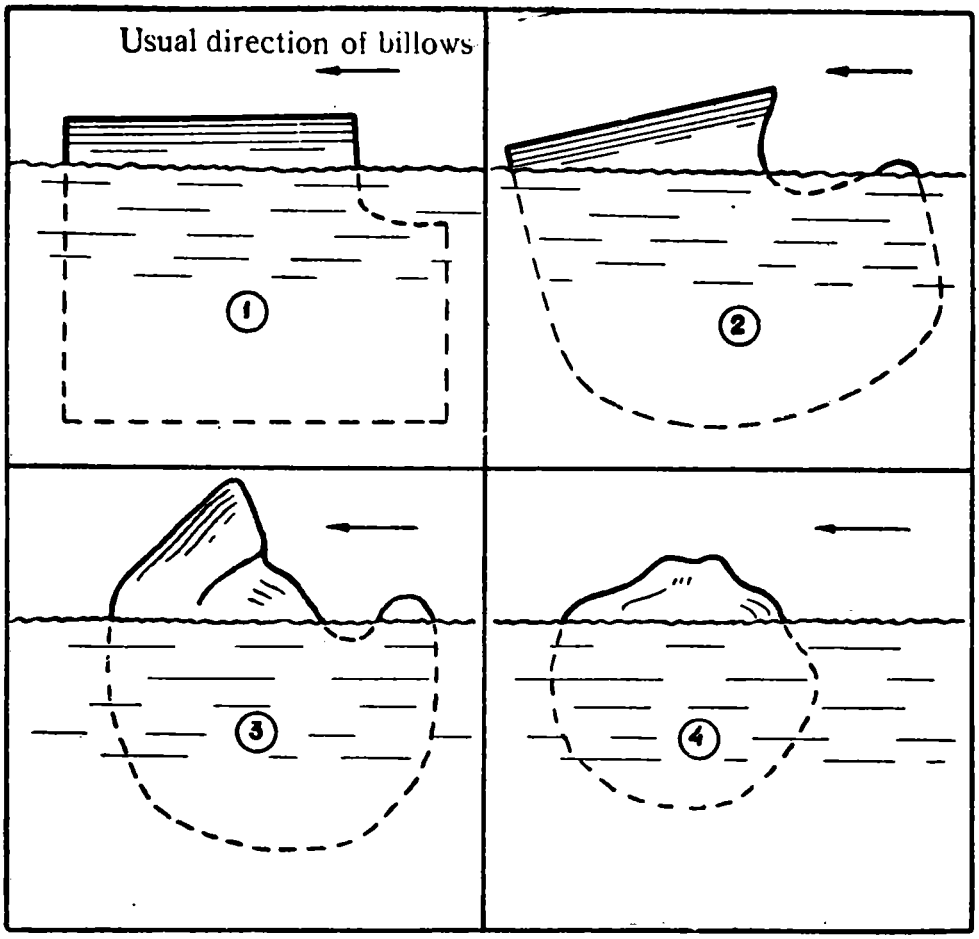
Secondary Forms

Tilting bergs have a flat sloping surface resulting from disintegration or inclination of tabular bergs of land-ice or barrier origin, their buttresses jutting out of the water. The tilting form is typical of the disintegrating bergs in the Antarctic. They are unstable and as disintegration continues they are liable to overturn and become round. Even an almost imperceptible inclination considerably alters the height of the tabular berg and that is what distinguishes tilting bergs from tabular bergs. Moreover, wave erosion creates under-water terraces jutting out several metres. Inclination eventually causes the edges of these terraces to rise to the surface. Therefore, it is more perilous for a ship to approach an iceberg when it is tilting slightly (that is, when its under-water terrace is invisible) than when it is leaning heavily. Terraces are always on the side that is raised. The under-water terrace created by wave action upsets the equilibrium of the berg and, rising to the surface, lifts its edge (see Fig. on p. 113). As the berg continues to tilt, it assumes a pyramidal shape.

Tilting bergs and pyramidal tabular bergs may be differentiated by their length and height above the surface.

The *round* icebergs are those whose surface is made smooth and round by weathering, water and melting action. This form is typical of old bergs in high latitudes where the melting process is slow and of bergs overturned in other parts of the Antarctic.

Disintegrated bergs are those of quaint shape created by the disintegration of ice. Typical barrier bergs are



Transformation of a stratified tabular berg (1) by billows into a leaning stratified berg (2), stratified mountain-like tabular berg (3) and overturned round berg (4). Drawn by the author in Antarctica in 1954

pyramidal and column-like forms created by the collapse of névé layers under the impact of wave action. The pyramidal form may also be the result of the heavy inclination of an iceberg. Horn-like and wing-like protuberances over the water are typical forms of glacier icebergs.

Observations in the Northern Hemisphere have shown that it is quite possible to judge by the degree of disintegration of an iceberg its draught and rate of drifting. Data on this is given in Professor Zubov's book *Arctic Ice* (published in 1945) and may be applied, with certain amendments, to Antarctic icebergs.

Groups of Icebergs

An accumulation of bergs resulting from current and wind action is a mass of ice bodies of different form, height and origin. It may be observed in pack-ice areas and convergence zones where, under favourable conditions, icebergs disintegrate most intensely.

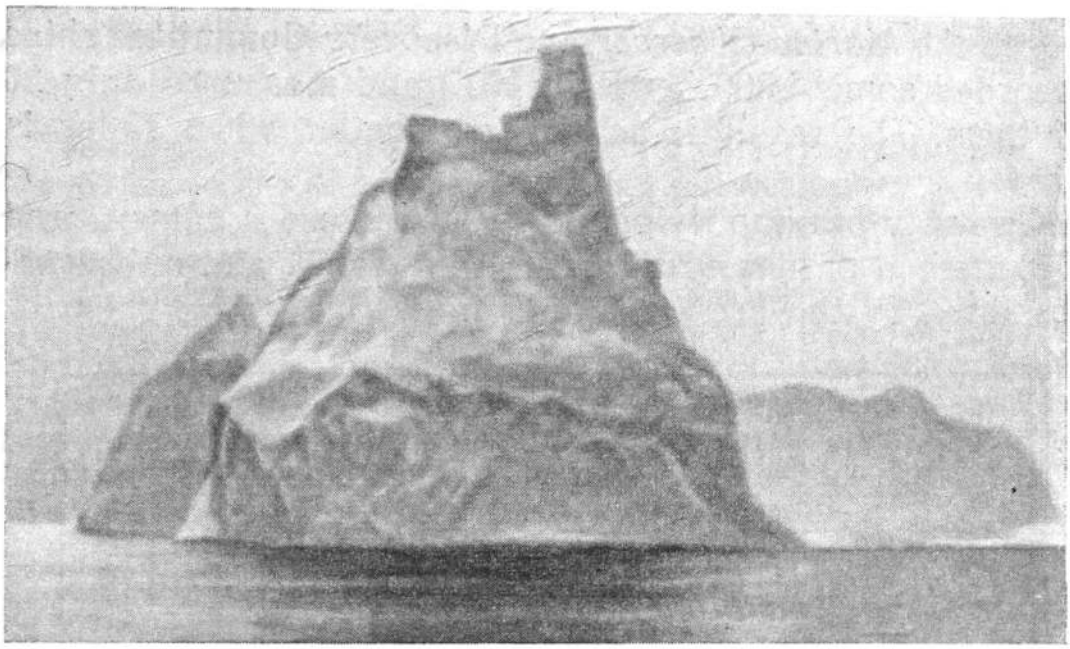
Such an accumulation may be in the form of a string of bergs resting on a shelf.

A *city of bergs*, or an *ice city*, is a group of floating ice masses of similar form, structure and origin. It is the result of the appearance of hundreds of new bergs calving from a drifting floe.

In using this scheme to determine the type, we should classify bergs simultaneously by origin and form, and note whether they are stratified, pyramidal, tabular, etc. A record like that contains the history of a berg's origin and life and even reveals the process of its disintegration (see Fig. on p. 113).

The longevity of an Antarctic berg depends on its origin. The most long-lived is the glacier berg. The barrier berg disintegrates faster and as it crumbles one may observe large masses of ill-compacted snow and névé breaking off. Sometimes a cannon shot is enough to make it break apart. As the barrier berg crumbles, it develops blunt, smooth angles and round caverns that look like grooves made on a beach by boulder-stones. That never occurs in the case of glacier bergs which disintegrate into what looks like huge solid rocks. The span of life of snowbergs is the shortest.

Polar literature says Antarctic bergs exist longer than those in the Northern Hemisphere, in fact over ten years. As an example we may cite a berg 90 metres high and almost 110 kilometres long which had been under observation for ten and a half years. It was first encountered in December 1854 in 44°S., 28°W., and met again in April 1865 in 40°S., 20°E. It should be pointed out, however, that long



Disintegrated barrier iceberg (from V. Buinitsky's book)

life is not a rule in the Antarctic. The ones that exist longest are those that do not drift to the low latitudes but move or remain stationary in pack-ice. Unless they are of exceptional size, bergs drifting into the open ocean disintegrate just as fast (one to three years) as the ordinary Arctic bergs,[1] with the Antarctic snow-bergs ever faster. An indirect evidence of the intense disintegration of Antarctic bergs in summer is the seasonal change in their northern boundaries.

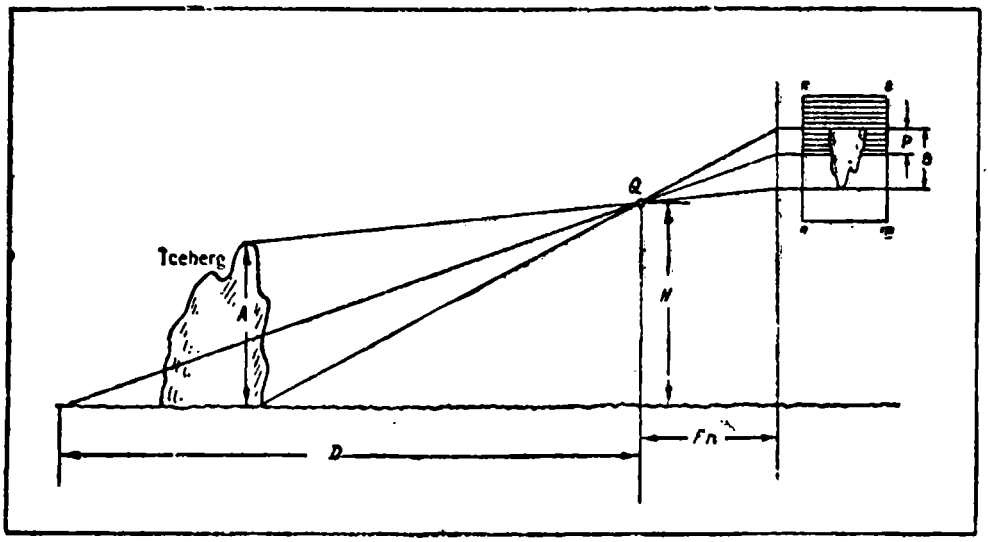
ICEBERG INVESTIGATIONS

Annual data on icebergs are collected by whalers. But since measurement of objects at sea is a long-drawn-out and difficult process, especially when undertaken from a small whaler or sealer in rough waters, the number of bergs measured is insignificant. The percentage measured by special scientific vessels is only slightly bigger. Accord-

[1] Arctic floes occasionally exist ten years too.

ing to the *Marine Observer*, the Discovery Committee ships recorded some 4,300 bergs in 1937 and measured only 20 of them. The result is seldom any better when radar is used.

One way of simplifying the job is to use a camera and this method of measuring bergs was tested, and quite successfully, by the present author in 1953.[1]



Measuring the height of an iceberg with a photo camera. *Q*—camera's lens, *klmn*—photograph

To obtain the dimensions of an object with the aid of a photograph it is necessary to have two things: the line of the horizon should be seen on the print and the object itself should be on the surface of water or ice.

The reliability of this method of measuring objects with clearly defined contours may be checked by several control shots, while the errors resulting from the tossing of

[1] The objects measured with the aid of a camera in the Antaretic in 1953-55 were chiefly icebergs, sea-ice formations and the spouts of whales.

Measuring the parameters of waves in the open sea with the aid of ordinary photographs proved much more difficult and the results less reliable because photographs do not show the voluminosity of waves.

the ship may be eliminated by photographing the object from the crest and then the trough of a wave.

Measurement of an object with the aid of a camera is based on the same principle as measurement with a perspectometer: the distance to the object is determined by its remoteness from the line of the horizon. The necessary condition for computation is to find the height of the camera above sea-level at the time the object is photographed (H) and the focal length (F) multiplied by the number of times the shot is enlarged (n). To obtain the dimensions of an object from a ready-made print (see Fig. on p. 116) or from an imprint on white paper it is necessary to measure the height (p) from the line of the horizon to the water-line of the object. After that the dimensions of the object are determined by the following formula:

$$A = H \frac{B}{p + \frac{nFH}{D}} \tag{4}$$

where A is the real size of the object;
B is the object's size on the print;
H is the height of the lens above sea-level at the time the object is photographed;
D is the distance of the visible horizon;
p is the distance on the print from the line of the horizon to the water-line of the object;
n is the number of times a shot is enlarged when it is printed;
F is the focal length.

The distance of the visible horizon, as every navigator knows, is determined by the following equation:

$$D = 2.08 \sqrt{H} \text{ miles} = 3{,}852 \sqrt{H} \text{ miles},$$

which takes into account the inclination of the visible horizon and the average effect of terrestrial refraction. Thus, the formula (4) may be given as:

$$A = H \frac{B}{p + \frac{nF\sqrt{H}}{3{,}852}} \tag{4a}$$

The formula (4) is based on optical relations shown in the figure.

To check whether the measurements made by the photographic method were correct Soviet scientists photographed the whaling ships and the *Slava* factory-ship and then calculated the dimensions of various parts of these vessels on the basis of the formula (4). After that

these parts were measured with a tapeline. The scientists then compared the measurements obtained by the photographic method (20 photographs taken in different waters and from different distances) with the measurements made on the spot. The results are shown in Table 1.

Table 1

Accuracy of Photographic Measurements in the Open Sea[1]

No. of photograph	Dimension of object in metres		Force of roughness and swell	Error in measurement in cm.	Error in measurement in per cent	Effect of error on measurement of 10-metre-high icebergs
	Real	On print				
1	0.98	0.97	2	—1	1.02	9.9 m.
2	1.80	1.87	3	+7	3.89	10.4
3	1.80	1.70	3	—10	5.55	9.4
4	2.20	2.18	3	—2	0.91	9.9
5	2.20	2.30	2	+10	4.55	10.5
6	2.20	2.20	2	0	0.00	10.0
7	2.20	2.10	2	—10	4.55	9.5
8	1.81	1.72	2	—9	4.97	9.5
9	0.98	1.00	1	+2	2.01	10.2
10	0.98	0.93	3	—5	5.00	9.5
10	0.96	1.00	3	+4	4.17	10.4
11	1.18	1.28	6	+10	8.50	10.8
12	1.16	1.07	6	—9	5.60	9.4
13	1.16	1.26	5	+10	8.60	10.9
14	1.03	1.26	5	+23	22.11	12.2
15	0.97	1.07	5	+10	10.03	11.0
15	1.03	1.05	5	+2	1.94	10.2
16	0.97	1.03	5	+6	6.20	10.6
16	1.03	1.15	5	+12	11.60	10.2
17	0.98	0.97	3	—1	1.02	9.9
18	0.94	0.97	5	+3	3.20	10.3
19	0.94	0.20	5	+26	27.70	12.8
20	0.97	0.87	5	—10	10.03	9.0

Average error = 7.6% Average height = 10.3 m.

The table shows that the error in measurement is below six per cent if the sea is not very choppy and that it is very much bigger, up to 27.7 per cent, if it is. In the latter case a 10-metre-high berg may

[1] Measurements made by the *Slava-15* whaler in 1953-55.

become 12.8 metres high when measured and an ice-floe of one metre in height—1.28 metres.

A difference like that is an exception and, as the last column of the table shows, it is not very important in serial measurements undertaken to determine average dimensions An error of this kind, however, is impermissible when measuring individual objects.

It is quite possible to reduce this error, resulting chiefly from the heaving of waves, to 10 per cent and less by photographing the object successively from the crest and the trough of a wave and then taking the average. Photograph 5 in the table was taken from the trough of the wave, photograph 7 from the crest, photograph 6 from the average level. If the average dimension of an object photographed from the crest and the trough of a wave differs by 0.5 metre from that photographed in calm waters, the error on a photograph taken from a height of 5 metres will be 10 per cent, and 5 per cent from a height of 10 metres. The difference should be limited to 0.5 metre.

It is also necessary to emphasize that the formula (4) may be applied only if the optical axis of the lens is not inclined vertically at the time the photograph is taken. In this case the line of the horizon will be in the centre of the shot. If it is E distance away from the centre, we can calculate the angle of inclination of the lens γ at the time the photograph is being taken on the basis of the formula $tg\ \gamma = \frac{E}{F_n}$. In the event of the inclination of the lens the dimensions B and p will be distorted on the photograph, but the angles between the rays passing through the lens from the corresponding objects in the area will remain unchanged. Hence the possibility of making use of a distorted print to determine the angles from the objects and, knowing the angles, to determine B and p. In this case, to determine vertical and horizontal distances on the print it is necessary to take different angles into account. Let us suppose that B_h is height, B_l is the length of the object in the photograph and A_h and A_l the corresponding dimensions in the area.

In determining the height of an object it is necessary to know angle α —the angle between the rays directed into the lens from the line of the horizon and the water-line of the object, and angle β —the angle between the rays from the water-line and top of the object. The angles α and β are computed with the aid of the magnitudes l and h, taken from the distorted print; l—the distance between the water-line of the object and the centre of the shot, and h—the distance between the top of the object and the centre of the shot.

The ways of computing angles α and β and the apparent magnitudes p and B_h (p and B_h with $\gamma = 0$) are shown in Table 2.

Table 2

Finding the Apparent Height of the Object and Its Distance from the Horizon on a Distorted Photograph Taken with an Inclined Lens

Position of line of horizon above or below centre ofprint	Formula for calculating angles			Formula for calculating magnitudes p and B_h with $\gamma=0$	
	γ	α	β	$B_h=$	$p=$
Above	$tg\,\gamma=\frac{E}{Fn}$	$tg\,(\gamma-\alpha)=\pm\frac{l}{Fn}$	$tg\,(\beta-\alpha+\gamma)=\pm\frac{h}{Fh}$	$Fn[tg\,\alpha-tg(\alpha-\beta)]$	$Fn\,tg\alpha$
Below	$tg\,\gamma=\frac{E}{Fn}$	$tg\,(\gamma+\alpha)=\frac{l}{Fn}$	$tg\,(\beta-\alpha-\gamma)=\pm\frac{h}{Fh}$	$Fn[tg\,\alpha-tg(\alpha-\beta)]$	$Fn\,tg\alpha$

According to Table 2, the following is the formula (4) for the measurement of the height of an object when the camera is inclined:

$$A_h = H\,\frac{tg\,\alpha - tg\,(\alpha-\beta)}{tg\,\alpha+\frac{H}{D}} \qquad 4b$$

The distortion of the horizontal dimensions of the object caused by the inclination of the camera may be corrected along the angles i and δ; —the angle between the directions towards the measured line and the centre of the shot; i—the angle between the directions towards the line of the horizon and the measured line. The angles i and δ are computed with the aid of magnitude M—the distance between the measured line and the centre of the shot.

The ways of computing angles i and δ and the apparent magnitude B_l (B_l with $\gamma=0$) are shown in Table 3. In determining length as well as height, the apparent magnitude p is taken from Table 2. Thus, according to Tables 2 and 3, the following is the formula (4) for the determination of the horizontal dimensions of an object when the camera is inclined:

$$A_l = \frac{(B_l)\,\text{incl.}\cos\delta}{Fn\cdot\cos i\left(tg\,\alpha+\frac{H}{D}\right)}. \qquad (4c)$$

Theoretically, the biggest permissible error in measurement, resulting from failure to take account of the camera's inclination at the time the photograph is taken, is 19 per cent of the height of the ob-

ject. That occurs when the focal length is 50 mm. and the film is 36 mm. wide.

In practice, however, this error is made very seldom. For instance, there were only a few cases when errors amounted to 5-6 per cent when the *Slava-15* whaler measured 100 bergs in the 1954-55 season.

Table 3

Finding the Apparent Length of an Object on a Distorted Photograph Taken with an Inclined Lens

Position of line of horizon and measured line on photograph	Formula for calculating angles		Formula for calculating magnitude B_l with $\gamma=0$ on the basis of the distorted magnitude (B_l) incl.
	γ	δ and i	
Centre of shot is between line of horizon and measured line	$tg\,\gamma=\frac{E}{Fn}$	$tg\,\delta=tg\,(i-\gamma)=\frac{M}{Fn}$	$B_l=(B_l)\,\text{incl.}\frac{Cos\delta}{Cosi}$
The measured line is between line of horizon and centre of shot	$tg\,\gamma=\frac{E}{Fn}$	$tg\,\delta=tg\,(\gamma-i)=\frac{M}{Fn}$	$B_l=(B_l)\,\text{incl.}\frac{Cos\delta}{Cosi}$
The line of horizon is between measured line and centre of shot	$tg\,\gamma=\frac{E}{Fn}$	$tg\,\delta=tg\,(\gamma+i)=\frac{M}{Fn}$	$B_l=(B_l)\,\text{incl.}\frac{Cos\delta}{Cosi}$

SEA-ICE

An important role in the formation of sea-ice in the Antarctic is played by snowfalls and especially by snow drifting from the continent in autumn, as well as by the old pack-ice off the shore which, though destroyed in summer, also contributes considerably to the formation of new ice. Heavy precipitation of snow on the water causes a rapid drop in its temperature and intensive intermixture of its layers. In the Weddell Sea early in April 1955, for instance, it resulted in the complete mixing of the strata

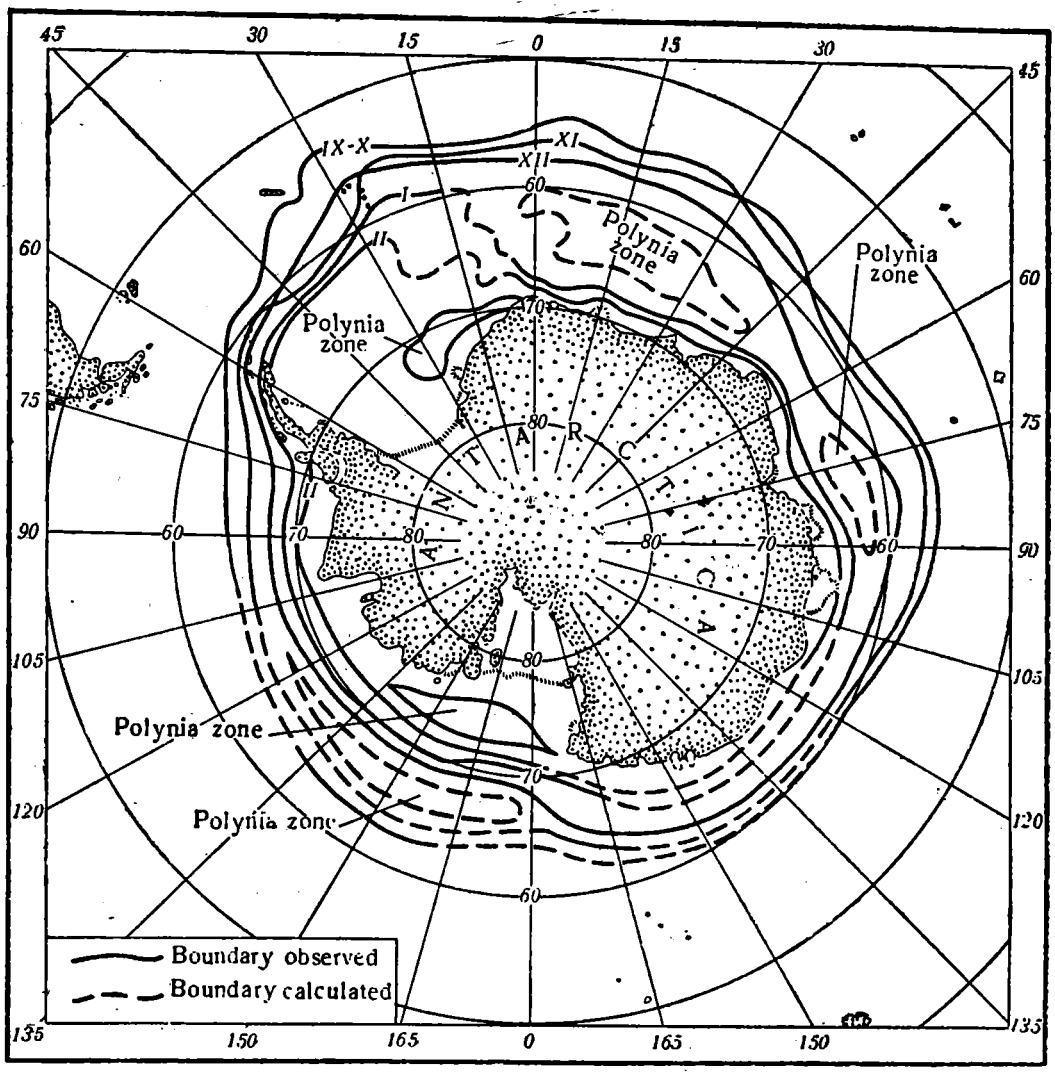
to a depth of 50-75 metres, while farther south, where there was much less precipitation, the autumn mixture affected layers to a depth of only 10-25 metres. Antarctic ice begins to form in late March or early April and goes through the same process as the ice in the Northern Hemisphere—from pancake ice to pack-ice between one and two metres thick.

The weight of the snow covering it in the first days of its formation often pushes new ice under surface. Its thickness increases by one to two and even three metres in a season. As it grows thicker and less saline, ice becomes more rigid and crumbles rapidly under the influence of a swell.

In summer the snow covering the floes freezes in contact with ice; thus, even in the warm season, the latter's thickness may increase.

Results obtained so far in the investigations into the mechanics and physical properties of ice, carried out by the Soviet *Slava* whaling flotilla, tally with those of similar research in the Northern Hemisphere. Even in high latitudes—for instance, in the Weddell and Ross seas—Antarctic ice is not an unbroken, static mass. As observations and drifting vessels have shown, it is always on the move.

Sea-ice moves northward more evenly than icebergs. Its average northern boundary extends farthest into the low latitudes in August-September, when it passes along 54°S. in the Atlantic, 56-59°S. in the Indian Ocean and 60-63°S. in the Pacific, where the Antarctic shores lie farthest south. In years of abundant ice this boundary is apt to extend two to nine degrees to the north. The southernmost points in February-March are occupied by the floes which weather the summer. In this period they recede towards the continent in all sectors, and only in the Weddell and Ross seas and to some degree in the Bellingshausen Sea do they remain considerably north of the coastline. In the Weddell Sea, winds and currents sustain a vast ice-tongue jutting out east from Graham Land to a point south of the South Shetland and South Orkney islands along 62-63°S. to 30°W.



Scheme showing the displacement of the ice boundary between September and February (after V. S. Nazarov)

South and east of this tongue, the sea is free of ice from 65-66°S. to 72-73°S.

In the centre of the Ross Sea there is a polynia (an unfrozen patch of water) between 200,000 and 300,000 square kilometres in size.

In these years of abundant ice the ice boundary may be very far from the coast, particularly in the areas of the Antarctic seas. Thus, north of the Weddell Sea it deflects by more than 300 miles and in some years passes in 50°S.

North of the Davis Sea it passes in 57°S., and north of the Ross Sea—in 63°S. towards the end of the summer.[1] Antarctic pack-ice which does not disintegrate in summer is often rotten, despite the impressive size of certain formations. In times like these, for instance, one can see the blood of a seal killed on a floe one and a half to two metres thick seep through into the water in a matter of minutes.

In spring, in years of both abundant and moderately abundant ice, pack-ice belts may be encountered drifting all over the ocean. Discrete spots and strips of ice are a typical feature of the Antarctic, like the vast polynias created by winds and currents. The "Circular Antarctic Polynia," along the continent's Atlantic coast, is sometimes 2,000 kilometres long and 500 kilometres wide.

The small number of meteorological stations and generally insufficient knowledge of Antarctica makes prediction of the seasonal movement of ice impossible. It is presumed, however, that ice movement in the Southern Ocean is greatly influenced by atmospheric pressure, winds and temperature on the continent.

According to Nazarov, the difference between Antarctic and Arctic ice lies in the fact that the latter recedes to higher latitudes in spring and the former is driven by the wind into lower latitudes, and that accelerates its melting. Ice charts and observations reveal that early in summer the Antarctic ice-front disintegrates at the speed of over 10 miles a day, and sometimes as much as 30.

A big role in the destruction of Antarctic sea-ice masses, especially big ones, is played by swells and that is why one rarely encounters large floes in the open ocean. Once a large floe has been broken up, the swell exerts little influence on ice, since minor floes, fragments and ice "mush" neutralize it without being affected themselves. On such occasions one can observe quaint-looking Antarctic floes melting away in the calm waters.

[1] See *Ice Chart of the Southern Hemisphere,* Naval Met. Br., London, 1942.

Constant westerly winds create phenomena which are typical of the Antarctic and which may well be called "ice roads"—strips of ice usually between seven and 15 metres wide, stretching away on the surface as far as the eye can see. These strips are made up of flat, water-soaked polyhedral ice forms, about one metre in diameter and deeply submerged (rising between three and ten centimetres above sea-level). It is quite possible that the formation of these ice strips is connected with the spiral motion of water particles in wind currents, known as "Langmuir's whirlwinds"[1] (N. N. Zubov, *Dynamic Oceanology*, Moscow, 1947, p. 328).

The "ice roads" created by the spring thaw are usually brightly coloured by plankton, with the hues ranging from yellow to red. In November and December these "ice roads" are many miles long and at least 50 per cent coloured by plankton.

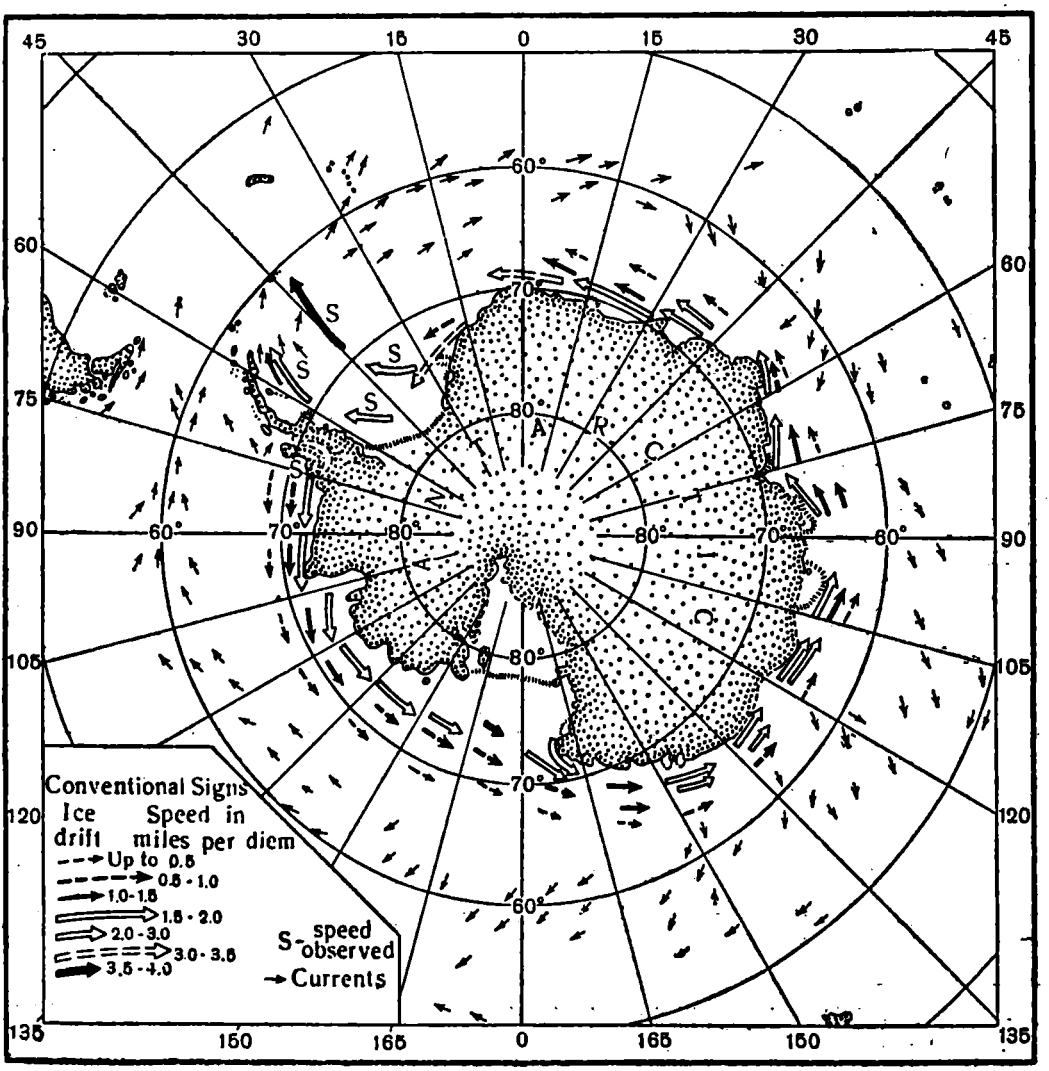
In spring one often encounters yellow and brown sea-ice in the Antarctic. These colours sometimes fringe the waterline of barrier bergs. The plankton get on ice in spring and summer and freeze in it in autumn. It is by the yellow layers of diatoms that one can tell the age of ice. Wordie suggests that because of constant movement the life span of ice in the Antarctic, the Weddell and Ross seas excluding, seldom exceeds one year. Yellow-layered ice, however, may be found in other regions, too, as we saw for ourselves off Princess Astrid Land.

The first organisms to develop in the Antarctic regions when the thaw sets in are the phytoplankton and then the zooplankton. The reason there is such an abundance of plankton at the ice-edge is that the thaw dissolves such nutrient salts as nitrates, phosphates and silica. In the

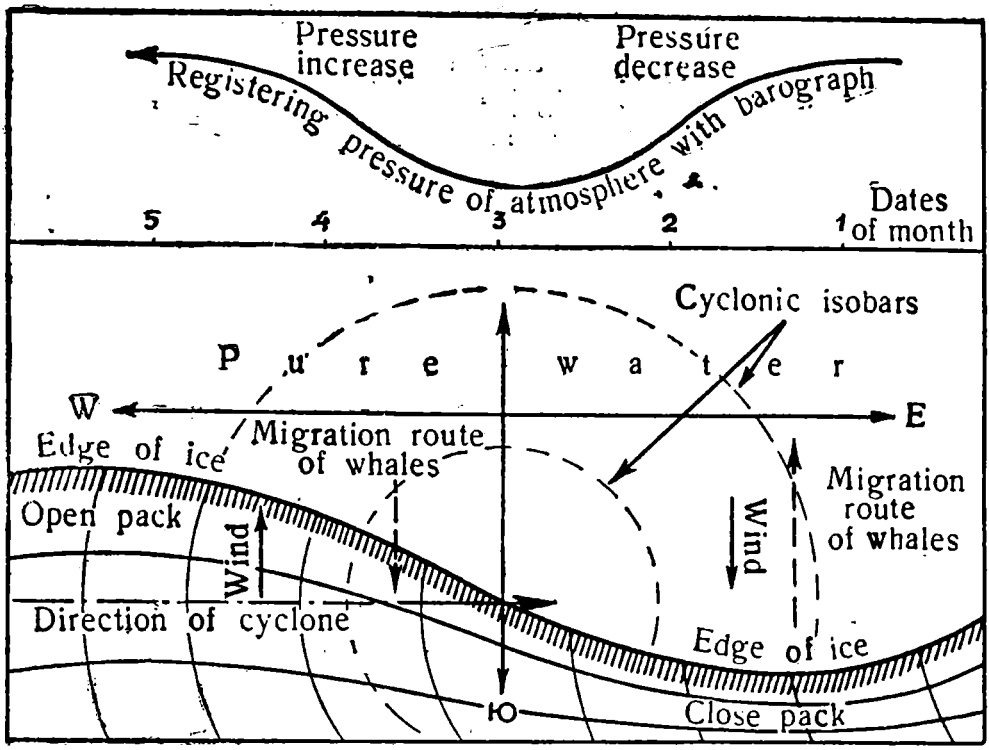
[1] Langmuir's whirlwinds, studied also by Woodcock, E. G. Arkhipova and N. Zubov, have horizontal axes, which are approximately parallel to the wind. The particles in the neighbouring whirlwinds move in different directions, and this creates in the upper stratum of the current alternating zones of convergences and divergences.

Northern Hemisphere, a considerable part of these concentrates is precipitated upon the ice. In the Antarctic, the process may be different because of the small content of pulverized mineral particles in the atmosphere and water. So far very little is known of the chemical composition of Antarctic ice.

It is possible that active development of life after the thaw sets in is also due to the structure and properties of



Scheme showing the ice drift (after V. S. Nazarov)



Scheme showing the movement of whales off the ice-edge during a cyclone, as observed by the author in the Weddell Sea in 1955

the molecules of ice, sometimes called "molecules of life"[1] (N. Zubov, *Antarctic Ice*, Moscow, 1945).

Most of the ice plankton are of yellow-greenish colour because of the chlorophyll in the cells of organisms. The plankton absorb solar heat and abrade ice. From afar, the depressions thus formed on the surface of ice look red or brown. A close look, however, will reveal that it is dotted with yellow-greenish phytoplankton. Among the Antarctic phytoplankton are the diatoms—minute plants oval or lentil-like in form. Being a factor making for plankton development, Antarctic sea-ice determines to a considerable degree the distribution of birds and whales in the Southern

[1] It is considered that chemically molecules of ice are more active than molecules of water.

Ocean. It has been observed that many whales, the Blue Whales, for instance, generally keep close to the ice, and that the appearance of birds like the Antarctic Petrel, and especially the Snow Petrel, is a sign of close proximity of ice.

It is not only through plankton development that sea ice influences the conduct of whales. Whalers have long known that the compression and movement of ice are apt to injure whales. The former sometimes makes it difficult for whales to rise to the surface to breathe and thus causes their death.

In 1951, Nazarov drew attention to the fact that there was a natural connection between the process of atmospheric pressure, the approach of storm and the movement of whales off the ice-front. As the wind grows stronger and the storm more imminent, he pointed out, the whales move away from the ice-front.

In 1955, however, when the *Slava* was operating in the Weddell Sea, it was observed that in certain cases before a storm whales move towards the ice-front, and not away from it. This may be attributed to the fact that during the storm meteorological conditions affect different sea-ice formations in different ways.

Professor Zubov writes that in a cyclone ice-floes go through the natural process of drifting, compressing, jamming and separating. It must be pointed out in this connection that the forces striking at the floes, and the floes themselves—before and after the centre of the cyclone has passed—move in opposite directions. According to Tauber, the centre of an Antarctic cyclone generally travels along the ice-edge (from west to east).

If we apply Professor Zubov's arguments to the Southern Hemisphere, we shall see that with a cyclone moving in the direction mentioned there will be compression of ice at the edge before the centre of the cyclone has passed (decrease of atmospheric pressure), and possibly ice-jamming. After the centre of the cyclone has passed

(increase of atmospheric pressure), compression of ice gives way to separation. Conclusion may thus be drawn that not every storm at the ice-edge is dangerous for whales—only that which causes compression of ice, that is, the storm in the frontal wave of a cyclone. It is only natural to assume that the storm in the tail-end of a cyclone, causing separation of ice masses cannot scare whales away from the edge, since discrete floes offer excellent shelter from storm waves. The storms in the frontal and tail-end parts of a cyclone may be distinguished by the rise and fall of atmospheric pressure (see Fig. on p. 127).

In 1955 the author observed the conduct of 117 whales off the ice-edge, and the movement of 103 corroborated the argument adduced above. With the approach of a cyclone, the whales move away from the edge; in the tail-end part, they move towards it. These observations, naturally, do not provide us with sufficient data. The issue, however, is of utmost importance for whaling and for that reason it is useful to discuss various schemes—that will permit us to test and elaborate them. We still have no clear-cut explanation of the reasons why whales move far from the ice-edge. This may possibly be due to distribution of plankton off the edge: near the ice one finds phytoplankton and some distance away zooplankton, which constitutes the main food of the whales.

SOUTHERN OCEAN WATERS

ANTARCTIC BASIN

Antarctic oceanology is a science of profound interest to geographers, for it is in the Southern Ocean that water masses form and their bottom currents start spreading northward and fill the oceans. According to the progressive theory of tides, it is in the Antarctic that the tidal wave forms. The vastness of the Southern Hemisphere's basin offers splendid opportunities for verifying various important oceanological theories based on the classical hydrodynamic assumption that the sea has neither bottom nor shores. Knowledge of the Antarctic Ocean is essential both for whaling and sealing purposes and for scientific expeditions operating in the region.

"Like a moat around a fortress," Charles A. Fleming writes, "the Southern Ocean encircles Antarctica and defends her secrets from the assault of human enquiry, and it is impossible to think of Antarctica without including the Southern Ocean, for every expedition to the far south must force its way across the 'Roaring Forties' and 'Furious Fifties' before picking a perilous course through the pack-ice to the threshold of the continent" (*The Antarctic Today*, p. 102).

In Russian polar literature the Antarctic basin and the other oceans extending to the southern latitudes are re-

garded as one whole.[1] Antarctic seamen, however, know very well how to distinguish its waters from those of the Atlantic and other oceans. Navigation conditions are quite unique and the climatic peculiarities and sea boundaries are well defined. *Slava* whalers have a picturesque way of describing the climatic conditions prevailing at the boundary of the water belt. "We're out of the ice cellar," they say as they leave the Southern Ocean. When the ships cross the "Roaring Forties" from the blue Atlantic, they find themselves in another world in the Southern Ocean—in a world of overcast skies and blizzards, icebergs and whales, fogs and albatrosses.

The Southern Ocean region, original and as different from the continent as it is from the regions lying north, should have a name of its own.

The first attempts in scientific literature to classify the south polar ocean belt were made in the mid-19th century. Since then it has been variably called Antarctic Ocean, Southern Circumcontinental Sea and Southern Ocean. The latter has become more established than the others.[2]

While in cases of new geographical discoveries explorers think up strictly scientific names, in those of the areas long since explored they have every right to use historical names even when they do not conform to the scientific classifications existing in various phases of our science. It should be noted, however, that our growing knowledge of the world's ocean belt, of the chemical composition of its waters, currents, biology, morphology and geology demands a more detailed classification. And, at any rate,

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[1] Others to voice the same opinion are the International Hydrographic Bureau (1950) and a number of American institutes. On the other hand, it is opposed by such eminent oceanologists as G.E.R. Deacon and H. U. Sverdrup, with the latter suggesting that the Pacific, Atlantic and Indian oceans are bays of the Southern Ocean.

[2] Of the Russian authors, Bellingshausen (1824) called it Antarctic Ocean. B. P. Alisov (1950), B. A. Zenkovich (1953), N. N. Zubov and D. I. Shcherbakov (1956) prefer Southern Ocean.

such an important and unique sector as the south polar belt must be included in this classification in one way or another.

This geographical problem will be eventually solved by scientists, but until then we may well use the two names that have become historically established: Southern Ocean and Antarctic Ocean.

Just as there is no definite northern boundary of Antarctica so is there no definite northern boundary of the Southern Ocean. In 1845 the Royal Geographical Society proposed to regard lat. 66°30′S. as the northern boundary of the Southern Ocean. Vallaux, on the other hand, draws the line at 35°S., Mac Ewen at 40°S. and Bourcart (on the basis of bottom water topography) at 60°S. (Bourcart, *Ocean and Sea Topography,* Russ. Ed., Moscow, 1953).

There are, however, many common factors determining the northern boundaries of the Southern Ocean and Antarctica. We agree with Buinitsky's point of view that, firstly, "the natural boundary of Antractica should coincide with the northern edge of the zone of typical Antarctic waters" and, secondly, "the borderline dividing the Antarctic waters proper from the water masses of the adjacent sectors of the Atlantic, Indian and Pacific oceans, is the zone of the Antarctic Convergence" (V. Buinitsky, *Antarctica,* Moscow, 1953). In this case, the area of the Southern Ocean with its seas[1] will exceed 38,000,000 square kilometres.[1]

The *Antarctic Convergence* or, as it has now come to be known, *Antarctic Confluence,* is the boundary of the Antarctic and subantarctic surface waters. Within the limits of the Southern Ocean, the Antarctic waters flow northward over a denser layer of deep water. Not being horizontal, the underlying stratum rises sharply from

[1] The area of the Arctic Ocean with its seas is slightly over 14,000,000 square kilometres.

north to south at the boundaries of the Antarctic. At this spot the surface water loses its dense-water base and sinks sharply under. Its place on the surface is then taken by the light water of the subantarctic zone. The boundary between these waters—the Antarctic Convergence—is a tortuous, unbroken circle passing through all the sectors of the Antarctic region and is best determined by the rapid change in the temperature of the water. Across the convergence, the temperature rises northward from 4° to 6° in summer and from 1° to 3° in winter.

We have cited the examples above to show that seamen always know when their ship crosses the convergence northward. Here is further confirmation by a participant in the *Discovery II* expedition: the boundary is readily determined with a thermometer, by water analyses, by study of plankton samples or by observation of dominant sea-birds. "But we, whether sailors or scientists," he writes, "know and will remember the convergence best in another way.... It was like passing at one step from winter into spring." (*The Antarctic Today,* p. 117.)

The boundary between the Antarctic and subantarctic surface waters varies in position from year to year and from season to season by up to 100 miles, but on the whole it is well defined and marks the limit to the northern range of many planktonic organisms, fishes and even bottom-dwelling animals. Fleming explains this by differences in the "rain" of detrital plankton north and south of the convergence. These differences lead to the fact that there is globigerina ooze north of the convergence and diatomaceous ooze in the south (*The Antarctic Today,* p. 118).

In the Atlantic and Indian oceans the position of the convergence is generally in 50°S. and in the Pacific—in 57°S. As we have seen, these positions on the whole border on the zone of ice and icebergs, which play a big role in the formation of the Antarctic surface water. The position of the convergence, however, is not determined by the

movement of ice, but by the flow of deep water, as first shown by Deacon.[1]

Most of the concepts aired in world polar literature about the character of oceanic circulation in the Antarctic were worked out before the war. The first comprehensive post-war work on hydrology in this region appeared in 1956 (Y. V. Makerov, *Antarctica*, Leningrad, 1956). Much credit in the study of the Antarctic Ocean is due to Deacon, who synthesized the data collected by the Discovery Committee, as well as the reports of the *Challenger* (1872-76), *Belgica* (1897-99), *Valdivia* (1898-99), *Gauss* (1901), *Antarctic* (1901-03), *Scotia* (1902), *Français* (1903-04), *Pourquoi Pas?* (1908-10), *Deutschland* (1911-12), *Norvegia* (1927-28) and other expeditions. Their reports were also reviewed later by H. Sverdrup, G. Koopmann and Y. Makerov.

Sverdrup and Deacon have both pointed out that the Antarctic water masses and dominant currents are "unusually clear-cut" (H. U. Sverdrup, M. W. Johnson and R. H. Fleming, *The Oceans, Their Physics, Chemistry and General Biology*, N. Y., 1940). The waters of the Southern Ocean have three layers, each of them of its own origin and with its own system of circulation.

Surface water in the Antarctic zone is replenished by warm deep water flowing from the north and by water formed by melting icebergs, precipitation and wind-driven snow from the continent. Makerov (1956) has calculated that the fresh-water content in the Southern Ocean is roughly as follows: average precipitation—22.7×10^3 cubic kilometres a year (60 cm); influx from the continent—1.2×10^3 cubic kilometres a year (considering that it is equivalent to precipitation over the continent); melting

[1] It must be pointed out that Deacon's proposition is not universally recognized. Sverdrup, for instance, believes that the light surface waters of the subantarctic zone are carried south by currents set up by differences in density due to temperature and salinity, whereas Antarctic water is carried north by the wind, and that the meeting of the two forms the convergence zone.

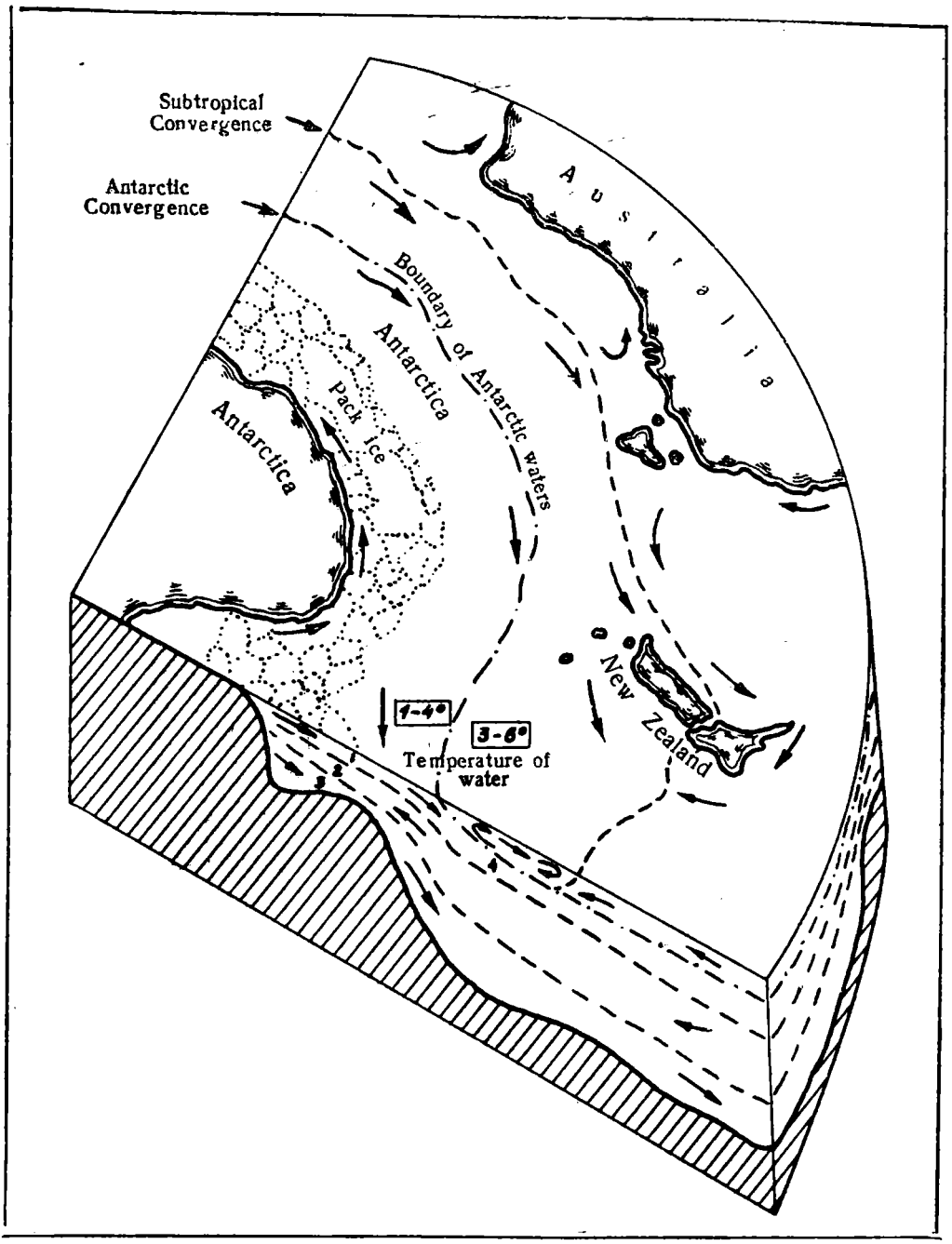

Diagram showing the circulation of Antarctic Ocean water (after C. A. Fleming, 1952)
1—Antarctic surface water; 2—Warm deep current; 3—Antarctic bottom current; 4—Antarctic intermediate current

and forming of sea ice—22.9×10^3 cubic kilometres; evaporation—12.4×10^3 cubic kilometres a year. Hence, the amount of the fresh-water content—13.6×10^3 cubic kilo-

metres a year. The amount of spring and summer melt water, Makerov says, is equal to the sum total of annual precipitation, annual influx from the continent and volume of the sea ice, namely, to 46.8×10^3 cubic kilometres. As said above, these figures are very rough.

The amount of precipitation for the whole of the ocean is obtained by interpolating the reports of different stations. The average thickness of thermic sea-ice[1] is taken as approximately 1.3 metres. The amount of evaporation is obtained by the extrapolation of data relating to the northern parts of the region. The amount of precipitation on the continent (considered equal to the influx from the continent) is taken from E. Kidson, who proceeded in his calculations from the humidity content of the air masses circulating over the continent.

There is very little data permitting a more detailed assessment of the composition of the Southern Ocean water. The Norwegian-British-Swedish expedition of 1949-52 reported that the melting away of shelf-ice (from the surface of a vertical barrier only) in the area where the expedition worked amounted to 36 cubic centimetres per centimetre of the shelf-ice's length.

If all the fresh water coming from precipitation and the melting of sea ice, icebergs and glaciers were to be evenly distributed over the Southern Ocean, it would form a layer over three feet thick.

In fact, however, the summer melt-water spreads in patches of warm and defreshened water near ice-formations on the surface of the ocean. The temperature at the depth between one and two metres along the ice-edge varies, according to Deacon, minus 1.9° C. to 2° C. and salinity from 33.5 to 34‰. North of the ice-edge, where there is greater intermixture, the Antarctic water is uni-

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[1] *Thermic ice*, according to Professor Zubov (1956), is ice formed of freezing water, as distinct from *pressure ice* which is formed of compacted snow.

form to a depth of from 55 to 85 metres. The warm layer and intermixture of water at this depth create an intermediate stratum delineating the boundary of winter and summer water. In winter, in regions of congelation, there forms a layer of homogeneous water upwards of 100 metres thick, with a temperature of minus 1.83°C. and salinity of 34.47‰. The drop in the temperature in winter to the freezing-point and below usually affects the water to a depth of 200 metres. This cold water flows from the southern boundary northward where it mixes, thus forming the upper layer of the Antarctic Ocean. This layer is thinnest at the line dividing the East Wind Drift in the inner part of the Antarctic zone from the West Wind Drift in the rest of the zone, that is, in 65°-70°S. The thickness of the layer here is about 70 metres, gradually increasing southward and northward to 200-300 metres in the convergence zone and to 390-700 metres off the coast. Sverdrup pointed out in 1933 that the homogeneous structure of this layer in winter made it quite possible for wind currents to affect water to a depth considerably exceeding 100 metres. In summer, on the other hand, the depth affected is only between 40 and 80 metres, this being due to stratification, as we have already said.

The upper layer is underlaid by warmer, denser and more saline water from the north—deep water presumably formed in different zones. According to W. Brennecke and G. Wüst, warm deep water originates in the subtropical region of the Northern Hemisphere, where it sinks from the surface in the subtropical convergence zone. It also mixes with the remnants of the water of Antarctic origin and with the waters of the Mediterranean and Red seas and, apparently, with the water of the Gulf of California.

The existence of the Warm Deep Current, or, as Sverdrup calls it, Antarctic Circumpolar Water, has been proved by all deep-water observations carried out south of the Antarctic Convergence. Its temperature is above

0°C. (up to 2.5°) and salinity upwards of 34.7‰ (up to 34.76‰). The current has its axis at depths ranging from 200-400 metres to 3,500. Its temperature is highest at a depth of 500-600 metres and salinity greatest at a depth of 700-1,300 metres.

Below 3,500 metres the Antarctic is filled with bottom water with a temperature of minus 0.4°C. and salinity of 34.66‰. Bottom water, it is assumed, is formed by the mixture of equal volumes of surface water, sinking from the Antarctic continental shelf as a result of its increased density in winter, and warm deep water. According to Sverdrup, the temperature of the first is minus 1.9°C. and salinity—34.62‰; the figures for the second are plus 0.5° and 34.68‰. The salinity of the continental shelf water is increased as fresh water is removed and salt is left behind when sea-ice is formed. Its density is 27.89, that of warm deep water 27.84 and that of bottom water 27.86.

Antarctic bottom water, Deacon says, forms in the Weddell Sea. Sverdrup, on the other hand, believes that some of it, though an insignificant amount, also forms in the Indian sector of the ocean. Both deny the possibility of bottom water forming in the Pacific sector.

New calculations in this sphere were made in 1956 by Makerov, who came to the conclusion that bottom water can form along the edge of the continent in all the sectors of the Antarctic. Unfortunately, we know almost nothing about the thermal balance of the coastal waters, especially about heat advection (which was not taken into account in the above-mentioned calculations), to judge which of the propositions is correct.

Each of the strata of the Antarctic water mentioned above, says Buinitsky, is "under observation in all meridians, and the water is homogeneous everywhere in the region bordering in the north on the Antarctic Convergence zone. The picture changes completely across the convergence. The water masses observed north of this zone, that is, beyond the boundaries of the Antarctic, are not homo-

geneous and are influenced by the water of the adjacent oceans" (G. Darwin. *The Tides and Kindred Phenomena in the Solar System*, Russ. Ed., Moscow, 1923, p. 46). This statement clearly confirms the assumption that the Antarctic water belt is not merely a southern extension of three oceans, but an oceanological object by itself. And it is difficult to call this object a sea, for a sea is always part of some ocean basin, and such is not the case here.

CIRCULATION OF WATER

Judging by salinity, temperature and oxygen content, deep water moves from the Weddell Sea eastward around the continent to the western shores of Graham Land.[1] This circumpolar motion is complemented by the northward movement of bottom water in all the sectors of the ocean. Moreover, in the region of Drake Passage and the Scotia Sea there is a local westward movement of bottom water which flows into the Scotia Sea between the South Orkneys and the South Sandwich islands, reaching, according to Wüst and Deacon, long. 60°-70°W.

Absolutely nothing is as yet known about the velocity of bottom water movement. Wüst, for one, held that bottom water does not remain under the surface for more than 300 years. H. Stommel, on the other hand, reported that analyses of deep-water samples, recently made by the C-14 radiocarbon method, revealed that bottom water could attain the age of 1,500 (H. Stommel, *The Anatomy of the Atlantic*, "Scientific American," Vol. 92, No. 1, January 1955, New York).[2]

Very little is also known about the seasonal and annual fluctuations in the character and strength of bottom cur-

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[1] Makerov (1956) says this motion is broken into three parts by submarine ridges, or Antarctic basins.

[2] The age of ocean water is counted from the time it sinks under the surface.

rents. Deacon cites several cases of bottom water in the Atlantic and Indian sectors, situated farther away from their source of origin, bearing traces of later submersion than the water nearer to the source of origin. These observations have been carried out in different years and for that reason one may well assume that there are annual fluctuations in the distribution of currents. The fluctuations discovered by Deacon may equally mean that there are additional places where bottom water originates and that its movement in the given regions is more complex than believed.

There is little data available on fluctuations over the centuries. L. Worthington, the American oceanologist well known for his work in the Arctic, compared the oxygen content in the deep water of the North Atlantic over the past 30 years and came to the conclusion that it was decreasing. Extrapolating the rate of this decrease, Worthington found that it began 140 years ago. Hence his conclusion that the formation of Antarctic bottom water is an impulsive and not uniform process. The last mass formation of bottom water must have taken place about 140 years ago. Climatic conditions in Europe in those days, he pointed out, were severe (*The Anatomy of the Atlantic*). Interesting details of fluctuations in deep-water temperature over the centuries are also given by W. L. Stokes in *Another Look at the Ice Age*, published by *Science*, No. 3174, in 1955. The author considers the low temperature of the ocean water a temporary interglacial phenomenon and says that the temperature in the ocean is highest in the ice-age periods and lowest in the interglacial eras.

Very much more is known about deep water circulation than about bottom water. The speed and direction of deep-water motion are determined by the dynamic method.[1] The

[1] The method of determining currents by the distribution of water density.

direction may also be gauged from the analysis of temperature and salinity. The presence of a warm and saline stratum between colder and less saline layers proves beyond doubt that there is a southern deep-water current.

In the subtropical zone warm deep water flows southward at a considerable depth, below 2,000 metres in 30°-35°S. On the borderline of the Antarctic zone, where it meets deep-water masses, it rises sharply to the surface. In the Antarctic zone, deep water continues its southward movement under the upper layer, at a depth of 200 and less metres.

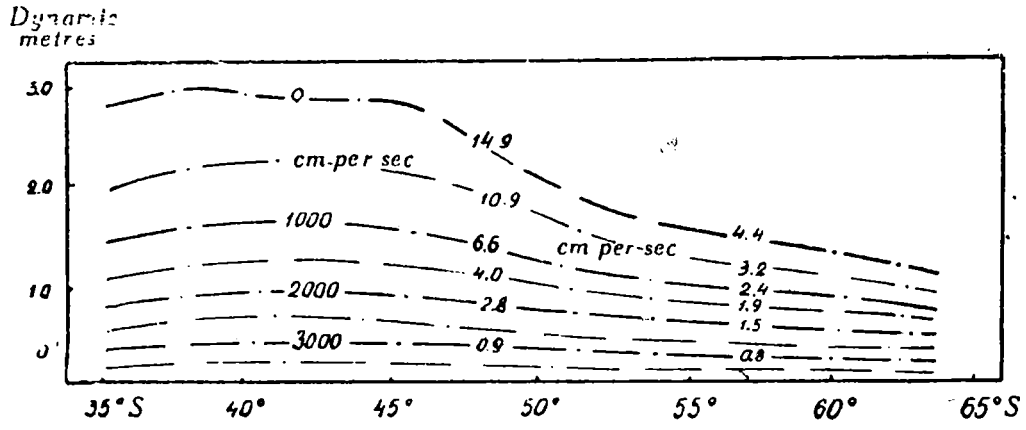
Sverdrup divides the warm deep water of the Antarctic into two parts: "intermediate layer" with temperatures ranging from 2° to 2.5°C. and deep-water layer proper, with the temperature on the surface and at the bottom of 0°C. and differing from that in the intermediate layer by 2°C. In the meridional section, the intermediate layer has the form of a wedge separating the Antarctic surface and warm deep waters from the direction of the subantarctic zone.

The incline of the isobaric surfaces (surfaces of equal pressure) shown in Sverdrup's scheme is evidence of the fact that deep water flows not only along the meridian, but also along the parallel, circling the continent from west to east. In this case, the greater the depth and the geographical latitude, the slower the movement. The greatest speed has been recorded in the belt around the Antarctic Convergence—11 centimetres per second at the depth of about 500 metres and 0.9 centimetre per second at the depth of about 3,000 metres.

The speed of the eastward flow in lat. 57° at the same depths are 3.2 centimetres and 0.8 centimetre per second respectively. The eastward flow around the continent of warm deep water and the simultaneous movement in the direction of surface and bottom waters are called "Antarctic Circumpolar Current." Dynamic charts of this current

have been drawn up by Deacon (for 3,000—0 decibars[1] and 3,000—600 decibars) and by Sverdrup, who used Deacon's data with modifications from *Meteor*. The dynamic chart here (after Deacon and Sverdrup) shows that the average movement of water between two dynamic points amounts to 20-25 million cubic metres a second.

Sverdrup's chart reveals that the westward flow off the continent takes place only in the cyclonic whirlpools in the Weddell Sea and may also be observed, though not



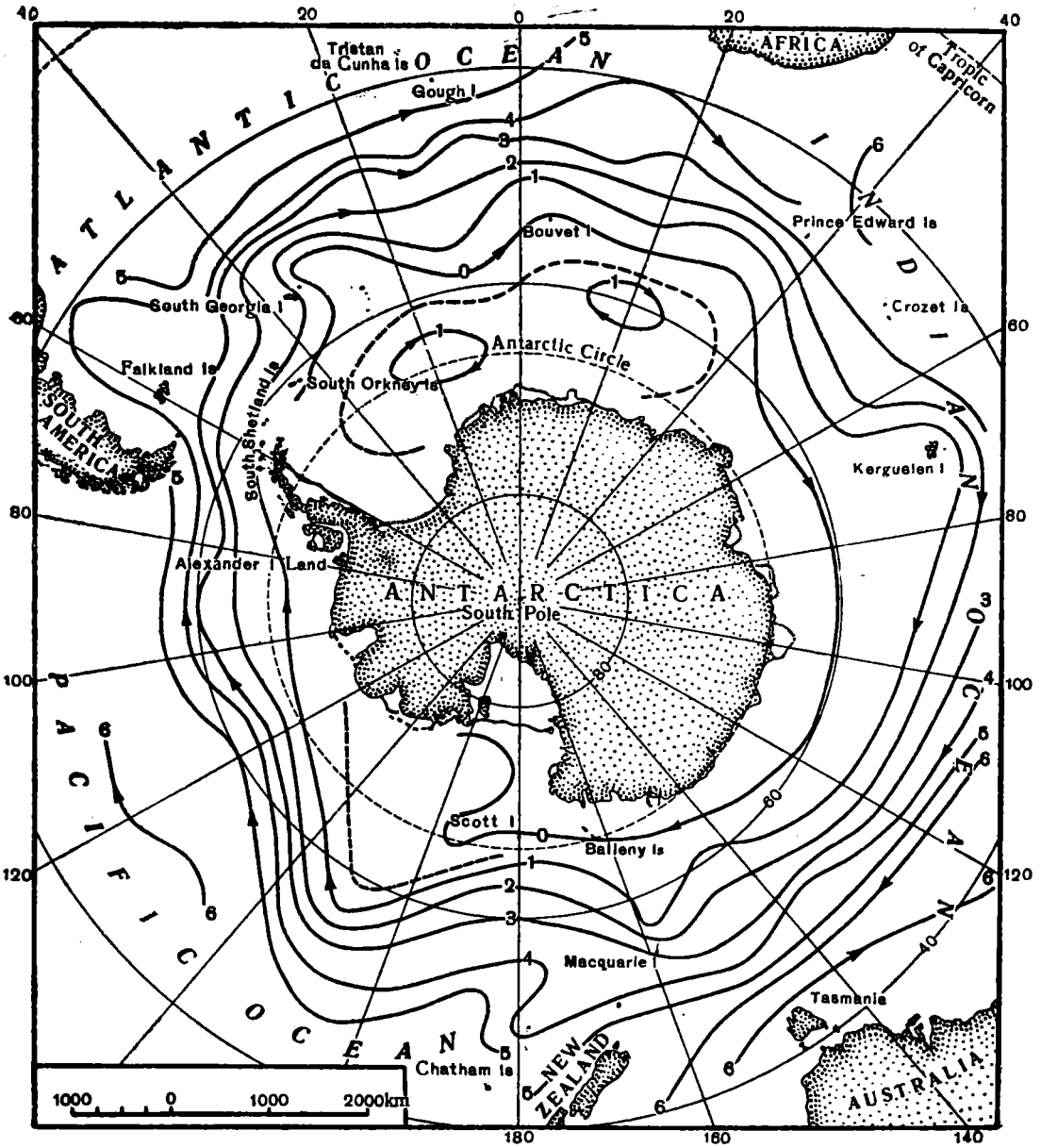
Profile of isobaric surfaces and velocity of currents in the Antarctic Ocean (after H. U. Sverdrup, 1946)

quite so clearly, in the Ross Sea. Rotation of the current in the Weddell Sea disturbs the equilibrium of temperature in the warm deep layer and plays a big role in the formation of bottom water.

The western part of the rotation has been named the *Cold* Deep Current of the Weddell Sea. Wüst, Brennecke and Deacon have shown that south of 66°S. in 30°, 20°, and 15°W. and 5° and 15°E. the temperature of the deep layer rises southward. North of 66° there is a mass of colder deep water flowing from the Weddell Sea.

Thus, warm deep water in the Atlantic sector flows south of 66°, mainly east of 15°E., and then west along the

[1] Unit of pressure. In oceanology it refers to the weight of a column of water about one metre high. Thus, a 3,000—600 decibar chart shows water movement at depths between 3,000 and 600 metres.



Dynamic chart of the Antarctic Ocean (after G. Deacon and H. U. Sverdrup, 1946). Movement of water from 3,000 to O decibars between two horizontals—20,000,000 to 25,000,000 m^3/sec.

southern boundary of the ocean. This westward flow of deep water off the continent takes place despite the action of the Goriolis force,[1] which is directed left in the Southern Hemisphere, and is due, according to Deacon, to the in-

[1] Deflecting force of the earth's rotation.

fluence of the East Wind Drift south of 66°. Farther, warm deep water effects a cyclonic circuit in the Weddell Sea, similar to the movement of surface water in this region. As it moves, deep water cools as a result of mixing with other layers (to 0.4°C. and less), though all along in the Weddell Sea it remains warmer than surface and bottom waters. Complete intermixture and destruction of the temperature maximum, Deacon says, may take place only off the western shores of the sea.

In many respects the cold layer moves in the same direction as bottom water. Part of it flows east, crossing the Atlantic, as we have shown, before it reaches 15°E. The other part flows north across the Scotia Sea or skirts the South Sandwich arc from the east. North of South Georgia this water plunges below the warm deep current.

The circulation of surface water is influenced mainly by the winds. The northern three-quarters of the Antarctic Ocean are in the West Wind Drift, while the inner zone off the continent is under the influence of the East Wind Drift, as Deacon calls the east wind belt of the Antarctic coast. It is to be pointed out that the East Wind Drift is considerably weaker than the West Wind Drift and is quite clearly defined only in the Atlantic sector.

In the West Wind Drift surface water moves northeastward at a speed of 5-10 centimetres per second. As it reaches the Antarctic Convergence, surface water flows over the steep layer of warm deep water "like a stream over a waterfall," to quote Deacon (*The Hydrology of the Southern Ocean*, "Discovery Reports," Vol. XV, 1937, p. 23). In other words, it sinks sharply along the slope of the denser deep water. After that the northward movement of the water continues in the shape of a sub-surface current called the "Antarctic Intermediate Current" (see diagram on p. 135).

The Antarctic Intermediate Current can be traced north to the subtropical and tropical zones as a poorly saline layer. After mixing, its salinity and temperature increase

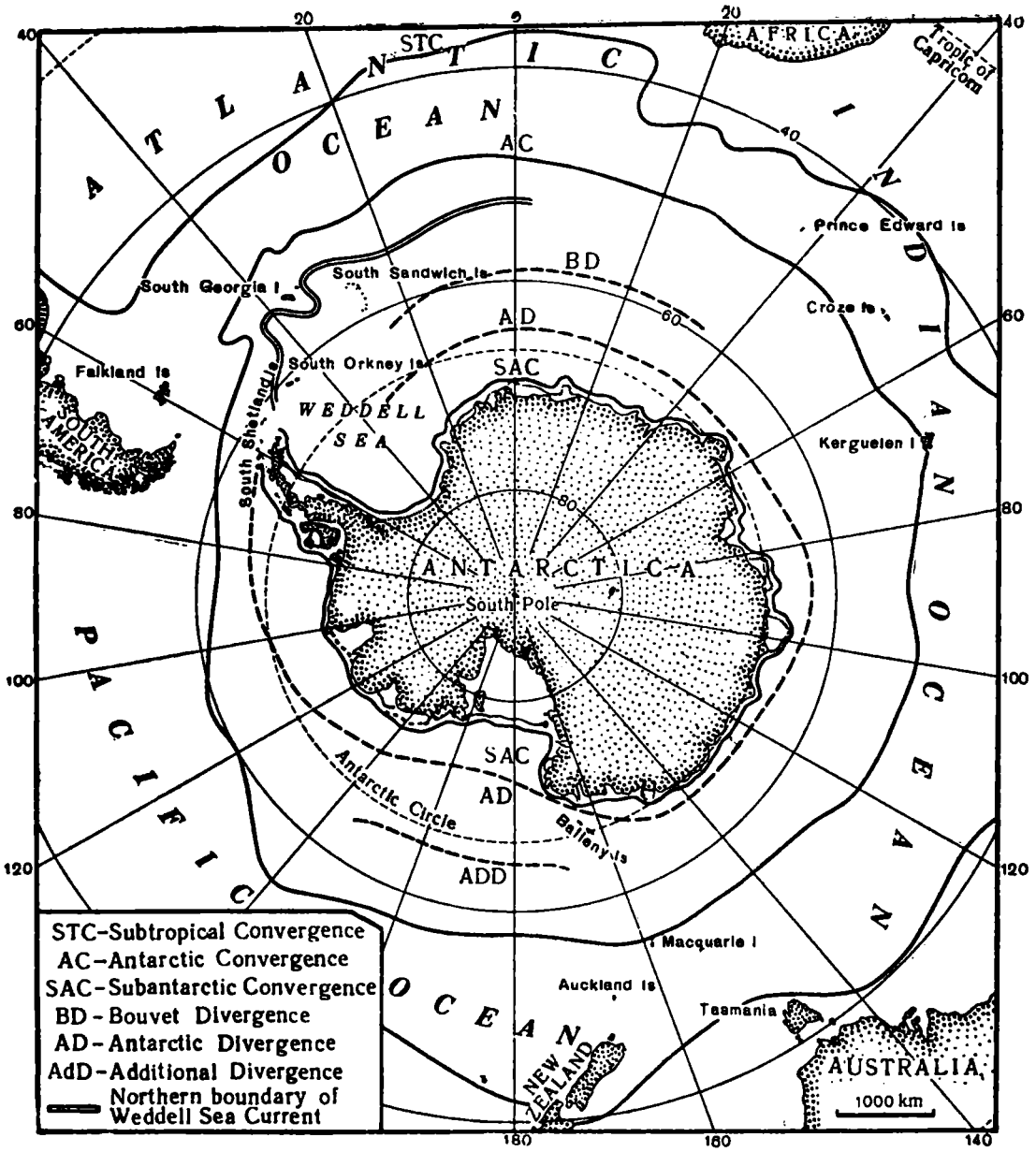
and oxygen content diminishes. These changes, however, are rather irregular, with both minimum and maximum temperature, salinity and oxygen content to be found along the meridians.

This is due to the different features characterizing the Antarctic intermediate currents when they form in winter and summer. Thus, the temperature is highest and salinity lowest in summer. The current formed in this season contains most oxygen.

Proceeding from these considerations, from the difference between minimum and maximum salinity and oxygen content, Deacon calculated the velocity of the Antarctic intermediate current and found it increasing northward: in 40°S. it is 1.3 miles a day, in 30°S.—1.5, in 20°S.—1.8 and in 5°S.—2.5. In brief, it takes water about four and a half years to cover the distance between the Antarctic Convergence and the equator.

The northernmost points of the Antarctic intermediate current's salinity have been traced to 24°20′S., 22°37′W. and 26°10′S., 16°42′W. The intermediate current reaches these places six or seven years after sinking under at the Antarctic Convergence.

The Antarctic Ocean hydrology has been comparatively well studied, but until recently scientists had been prone to regard lightly the influence exerted by meteorological factors on circulation. It was assumed, for instance, that on the coastline the wind drifted westward and north of the 65th Parallel—eastward. The change in the wind drift creates an almost circumpolar Antarctic divergence in lat. 62°-75°S. North of the divergence and all the way to 50°-45°S. distribution of wind force was generally assumed to depend, linearly or sinusoidally, on the geographical latitude of the locality. To a considerable degree, this gap has recently been filled by G. Koopmann, whose calculations show how much the wind-driven movement of water depends on atmospheric pressure in Antarctica (*Entstehung und Verbreitung von Divergenzen in der ober-*



Sketch-map of convergences and divergences (after G. Koopmann, 1953)

flächennahen Wasserbewegung der antarktischen Gewässer, Hamburg, 1953). Making use of whale investigation records, the synoptic charts of South Africa's Weather Bureau and many other sources, Koopmann succeeded in drawing a detailed chart of atmospheric pressure for an area extending from 25° to 75°S. Proceeding from the

gradient of pressure to the velocity of wind and wind-driven movement of water, he came to the conclusion that the Antarctic Divergence was not the only well-defined boundary of divergent currents, and that there was a similarly well-defined zone in lat. 60°S. in the Atlantic sector. On the sketch-map it is marked BD (Bouvet Divergence). In the Pacific Ocean off the Ross Sea, Koopmann draws the Antarctic Divergence in 75°S., that is, 10° south of where it was believed to be. In the place of the former position of the Antarctic Divergence he draws an additional divergence (marked AdD on the sketch-map). CC on the same sketch-map signifies Coastal Convergence, created by the East Wind Drift. The position of the Antarctic Convergence (AC), as Koopmann shows, coincides with the big fluctuations in the wind drift.

One of the comparatively new branches in the study of the Antarctic is coastal circulation off shelf-ice. Quite a bit in this sphere has been done by Sverdrup in the course of the 1948-52 Norwegian-British-Swedish expedition to Queen Maud Land. His dynamic chart of the coastal area

Table 4

Maximal Convergences and Divergences According to Koopmann

Latitude	Fluctuation in atmospheric pressure in millibars per 1° along meridian 0°	Difference in wind-driven movement of water of 1·10⁴ cm³/sec. over 1 cm of surface	Convergences and divergences of currents
27.5° S.	0.2	—0.62	
32.5°	0.0	2.47	SC
37.5°	0.8	0.20	
42.5°	1.0	0.13	
47.5°	1.2	1.51	AC[1]
52.5°	1.8	—1.77	
57.5°	1.4	—2.20	BD
62.5°	0.4	—1.21	AD
67.5°	—0.8	—0.25	(CC)
72.5°	—1.0		

[1] The latitude of the Antarctic Convergence at 0° Meridian is 49° S.

has permitted to determine the westward flow off the Maudheim Shelf-Ice. Sverdrup has computed that the volume transported towards the shelf-ice amounts to 8,500 cm^3/sec. through a vertical section of 1 cm. On the average, this water brings 2,450 calories per second to the ice shores. Estimating that 10 kilometres off the coast water sinks uniformly, Sverdrup has calculated that the speed of the vertical flow along the shelf is equal to 0.85×10^{-2} cm/sec. Thus, it takes surface water twenty days to sink to the depth of the shelf-ice. Supposing 12 per cent of the heat content in the water brought to the coast is spent on the melting of the shelf-ice, it is enough to balance the annual accumulation of snow. Sverdrup has also computed the velocity of the tidal current off the shelf-ice and found it to equal 18 centimetres.

TIDAL CURRENTS

Tidal currents in the Southern Ocean are sufficiently clearly defined only in the immediate vicinity of the coast and in narrow straits where their velocity usually ranges from about 0.25 to 0.75 metre, and sometimes even to about two metres, per second. Beyond the coastal region, they are superimposed by ocean currents caused by the effect of the prevailing winds.

The rise in sea-level is generally small, slightly over one metre. Moreover, tidal fluctuations can be fully nullified by the action of on-shore and off-shore winds which sometimes raise or lower the level of the ice-free coastal waters by as much as 3-4 metres. Currents play an especially important role off the edges of land-fast ice. Experience has shown that when a ship cannot break her way to the continent to land an expedition, the landing may be effected with the aid of weasels across the shelf, provided it has not been crevassed by the tides.

Tidal currents in the Southern Ocean began to interest

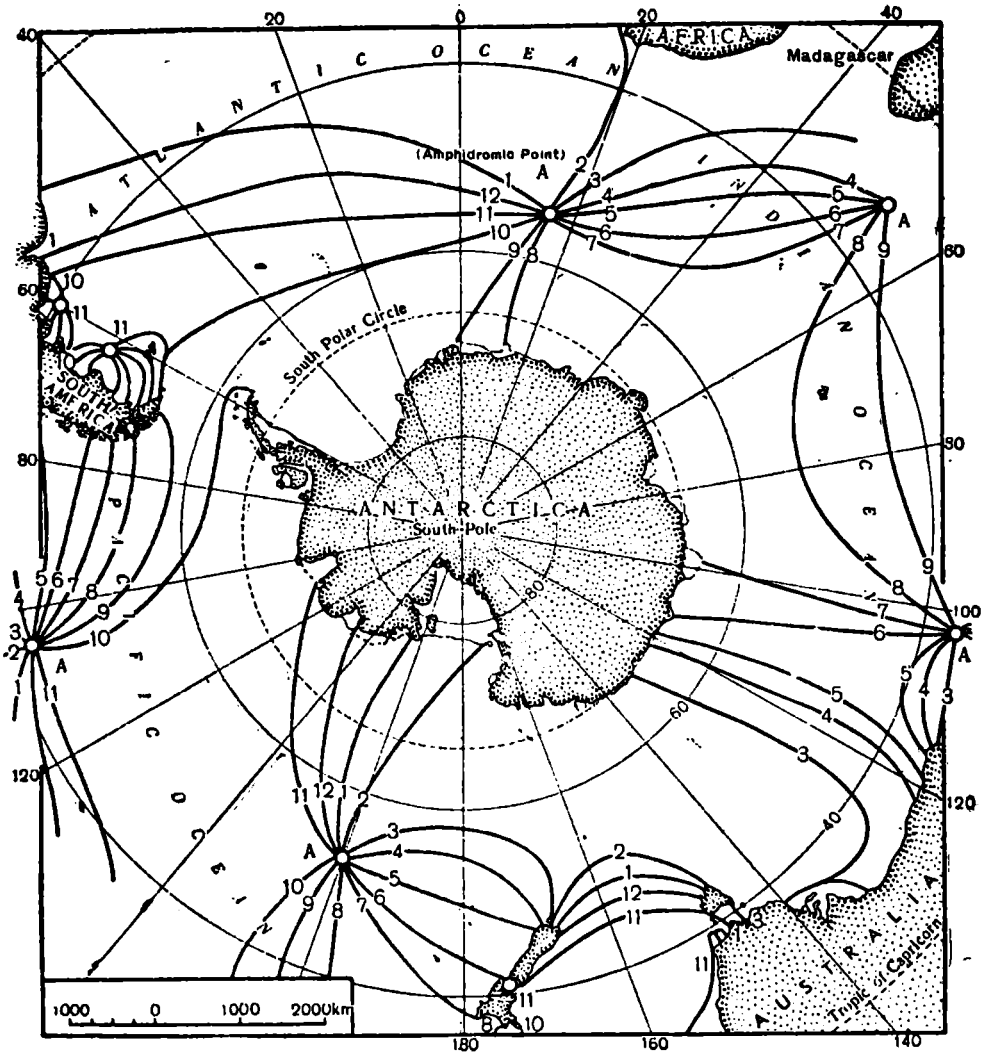
geographers, and not only for navigational reasons, long before the first expedition had landed on the continent.

As a matter of fact, several decades ago scientists regarded the Antarctic basin as the birthplace of the tidal wave. According to George Darwin's classical interpretation of this theory (1897), the biggest tidal waves are caused by the attraction of the moon and sun in the Southern Ocean and move eastward around Antarctica. A wave formed in the Pacific or Indian sector of the Antarctic causes a new wave in the Atlantic sector and as this latter wave moves northward it mixes, Darwin says, with the smaller local waves of the Atlantic Ocean. It is for that reason, he adds, that the rise of water we see off the European coast depends more on the rise that takes place two or three days earlier in the Pacific and Indian oceans than on the direct action of the Moon (George Darwin, *The Tides and Kindred Phenomena in the Solar System*, Moscow, 1923, Russ. Ed., p. 143).

The big part played by the Antarctic basin in the formation of tidal waves was also emphasized in latter-day polar works. In 1935, Vallaux pointed out that there was "no other ocean where precise and rather numerous observations of tides were as of great interest as those in the Antarctic" (C. Vallaux, *Geography of the Seas*, Moscow, 1948, Russ. Ed., p. 70). Darwin's theory of the development of tidal currents in the Southern Ocean predominated only until the time when scientists began investigations in the Antarctic water belt itself.

Observations of tides in this region were, as far as it is known, first carried out by a German expedition aboard the *Gazelle* in 1874-76, and later by the Nordenskjöld, Drygalski, Scott, Bruce, Shackleton, Larsen, Rymill, Byrd and other expeditions. Permanent observation stations were set up at various points of the Southern Ocean and today there are more than ten of them south of the 60th Parallel.

The very first data obtained revealed that Antarctic



Sketch-map of the principal lunar semidiurnal tides (from G. Dietrich, 1944); A—amphidromic point

tides were of a far more complicated character than classical tidal theories would have us believe. And as information accumulated, there appeared new schemes of the development of tidal phenomena in the Antarctic and new charts on the distribution of tidal waves. But as the number of observations was, on the whole, insignificant, the data obtained by each successive expedition often led to the precision, and sometimes even to radical revision, of the previously accepted concepts.

In 1900, the American oceanologist Rollin Harris showed that tidal oscillations in the area of Tierra del Fuego did not spread westward, but eastward, that is, from the Pacific into the Atlantic through Drake Passage.

R. Sterneck's map of 1922 shows that cotidal lines along almost the entire stretch of the Antarctic basin displace eastward.

On Dietrich's sketch-map (1944), flood tides skirt Antarctica in the same direction as shown by the classical tide theories, that is, from east to west. However, the explanations of tidal waves given by Dietrich, Sterneck and Harris differ substantially from that offered by Darwin. All three claim the tides are the result of several systems of standing waves. In these systems the cotidal lines rotate clockwise and counter-clockwise around the main points with standing water levels, that is, around amphidromic points.

On Dietrich's sketch-map of the principal lunar semidiurnal tides the amphidromic points are located in the zone between 50° and 30°S. The tidal waves to the north travel eastward and those to the south—westward circling around Antarctica in half a lunar day. This is confirmed by the fact that during the semidiurnal tide at Graham Land there is low water at Wilkes Land.

It should be pointed out that the above-mentioned schemes of tides are highly problematic and the later ones in some cases are not accepted by the scientists any more than the earlier ones.

The latest observations of tides to be published were carried out by a French Antarctic expedition at three points on the coast of Adélie Land in 1950-52 (Bertrand Imbert, *Nouveaux enregistrements de marée en Terre Adélie*, Paris, 1953). Analyzing the data they had collected, the French scientists sketched a new map of tides in the region south of Australia and New Zealand. They also arrived at a new conclusion on the movement of the tidal wave in Drake Passage: in the northern part of the passage

it proceeds from the Pacific into the Atlantic and in the southern—the other way round.

At present the British Admiralty issues tide tables giving advance information as to the time and height of high water at 21 points of the Antarctic, one-third of them off the coast of Graham Land. According to these tables, the tides at the northern extremity of Alexander I Land are characterized by diurnal inequality. Their amplitude is about 30 centimetres.[1] Tides showing diurnal inequality have been observed farther north along the western coast of Graham Land to approximately the 65th Parallel. Here amplitude increases to 60 centimetres. North of 65°S. to the extremity of Graham Land and off the islands in the Atlantic sector of the Southern Ocean the tides are characterized by semidiurnal inequality. The amplitude is greatest, almost 1.3 metres, at the northern extremity of Graham Land (Hope Bay). Maximum amplitude, however, can be much greater. At Desolation Island, when the moon's declination is at its maximum or at its minimum, it can be as much as 3.7 metres.

Semidiurnal tides and tides of semidiurnal inequality may be observed off the islands in the western half of the Indian sector of the Antarctic (Kerguelen and Heard islands), where the amplitude is 0.5-1 metre.

Tidal oscillations in the Davis Sea are now being studied by the Soviet Antarctic expedition. In the area of Mirny, at the time of the moon's maximum and minimum declination, the greatest amplitude recorded in the case of syzygian tides has been 1.8 metres. The character of the tides varies from diurnal to semidiurnal.

Off the coast of Adélie Land and King George V Land the tide shows diurnal inequality, while off Ross Island it is diurnal. The respective amplitudes are 0.5-0.6 and 0.7

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[1] Diurnal tide implies one low and one high water during the lunar day and semidiurnal tide—two low and two high waters. Amplitude means elevation of high water above mean sea-level.

metre. The tide at Macquarie Island is semidiurnal with an amplitude of 0.5 metre. The section of the ocean between the Ross and Bellingshausen seas has been studied very little.

Below are the average figures on the tides in the Antarctic, compiled from the British Admiralty's tide tables for 1955.

Table 5

Character and Amplitude of Antarctic Tides

Locality	Latitude	Longitude	Predominating character	Amplitude in metres
Marguerite Bay	67°11′S	67°00′W	Diurnal inequality	0.3
Argentine isls.	68 15	64 16	" "	0.5
Pettermann I.	65 10	64 14	" "	0.4
Port Lockroy	64 50	63 31	" "	0.5
Andwerd Bay	64 47	62 43	" "	0.6
Nansen I.	64 33	61 57	Semidiurnal "	0.8
Deception I.	62 58	60 34	" "	0.9
Hope Bay	63 24	56 59	" "	1.3
S. Orkneys isls.	60 44	44 39	" "	1.0
S. Georgia I.	54 30	36 30	" "	0.5
Heard I.	53 01	73°23′E	" "	0.5
Kerguelen I.	49 22	70 00	Semidiurnal	1.0
Port Martin	66 50	141 25	Diurnal inequality	0.5
Cape Denison	67 00	142 40	" "	0.6
Ross I.	77 49	166 45	Diurnal	0.7
Macquarie I.	54 31	158 58	Semidiurnal	0.5

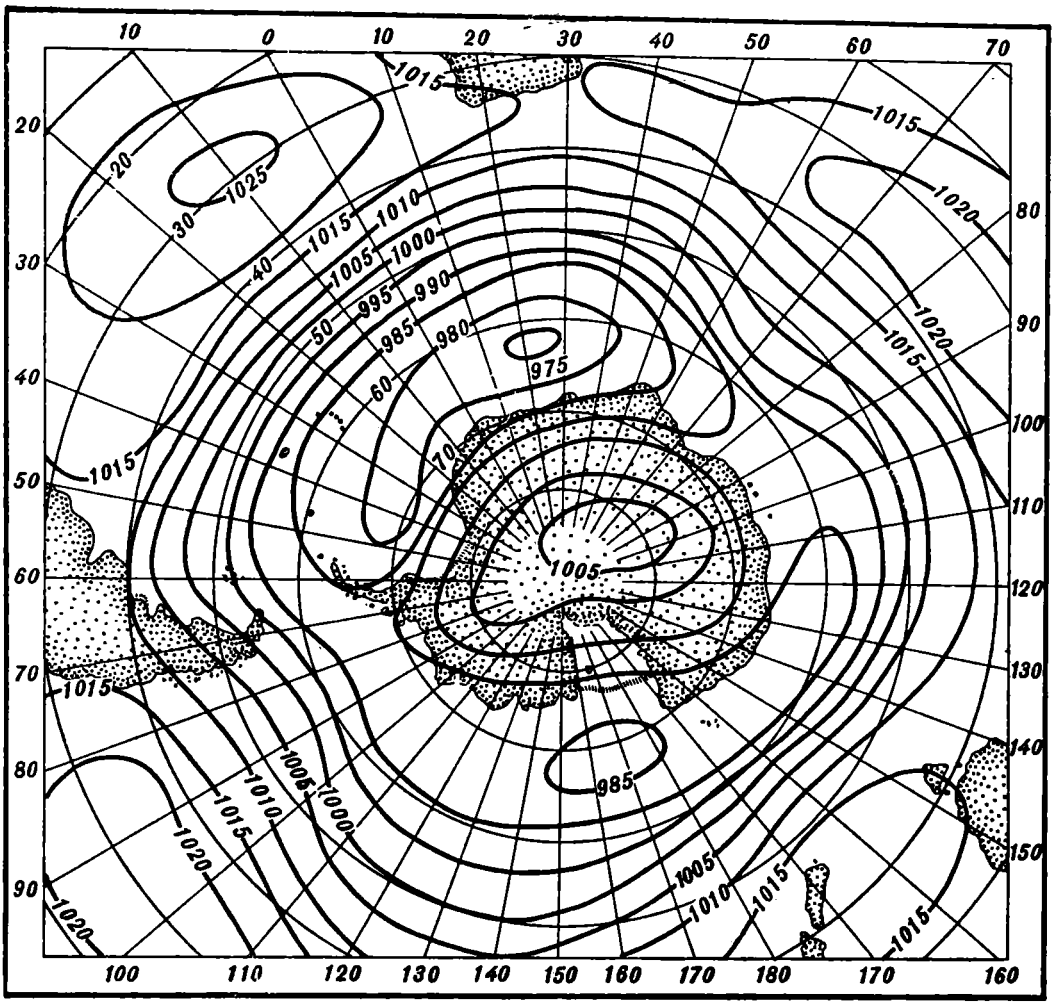
CLIMATE

ATMOSPHERIC CIRCULATION

Meteorological processes in the Antarctic region are characterized by the peculiarities of its geographical position and the distribution of its water and continental masses. The main climate-forming factor of Antarctica is the negative radiation balance. The Antarctic constantly disturbs the Earth's thermal balance. The continent is surrounded by a ring of high pressures of thermal origin, fringed by a zone of depressions of the Southern Ocean. Another, less stable, ring of high atmospheric pressure of dynamic origin passes north of the Antarctic surface waters in the subtropics, in 20°-40°S. (see sketch-map on p. 155).

The interaction of the zones with different characteristics and different movements of air masses creates the *Polar* and *Antarctic* fronts. It is at their edges that the cyclones originate, moving in endless series from west to east-south-east at a speed of more than 40 kilometres an hour. These cyclones are the most characteristic feature of the meteorological processes in the Southern Ocean. Series of several cyclones are often disrupted by minor intrusions of air masses of anticyclonic structure. The weather processes in the ocean, however, are not determined by these intrusions, but by the movements of depressions.

Although the small number of meteorological stations



Average pressure at sea-level in January 1951 (after G. M. Tauber)

in the Antarctic region does not permit a thorough study of the weather processes there, many successes have been achieved latterly: S. P. Khromov's analysis of deformation fields on medium pressure charts (1940) and Tauber's cyclone trajectories (1955) enabled them to determine the positions of the Polar and Antarctic fronts. In the Atlantic sector, the Polar Front moves from the shores of South America east-south-eastward, first in 40° and then in 50°S. Southeast of Africa it breaks and resumes its movement from the southern extremity of the African Continent in a southeasterly direction to 60°S. The Antarctic Front passes by the edge of the Antarctic Continent,

changing its position from 60°S. in winter to 70°S. in summer. It is less known than the Polar Front and some authorities claim that it is not a complete ring but a series of segments off the Antarctic shores.

In the Southern Ocean, the formation of climate depends chiefly on the conditions of circulation, in which Antarctic Front cyclones, moving in 60°-70°S., play an important part. Tauber is of the opinion that the seasonal position of the trajectories of these cyclones fully accords with the changes in the position of the ice-edge. The centres of the cyclones in most cases pass along the margin, but their edges sweep over vast expanses of the ocean to the north. Low clouds and overcast skies, frequent precipitation and mists, and the strong winds in the "fifties" and "sixties" are all usual consequences of Antarctic Front cyclones. Rapid changes and complicated synoptic charts make weather predicting a difficult task. With the fall of atmospheric pressure the wind usually alters its direction to north, northwest, and intensifies to storm force. As the pressure rises, the wind drops, though in the tail-end of a cyclone the rise of pressure is accompanied by extremely violent storms moving from west-south-west, followed by brief spells of clear weather. The frontal wave, on the other hand, is characterized by precipitation and dense fogs. In 1954-55, the *Slava* flotilla was caught in 41 storms in the Antarctic, and 22 of them were featured by a rise of pressure in the tail-end of cyclones. There were also simultaneous storms in the frontal and tail parts with brief spells of calm in between.

Difficulties in the meridional flux of air to the low latitudes through the "roaring forties" and the movements of cold air masses into the ocean from the Antarctic continental anticyclone constitute an important factor in preparing synoptic charts for the Antarctic.

The baric structure of this anticyclone remains a mystery in many respects. Some authorities hold that high pressure does not extend to the entire continent, but only

fringes it. This assumption is based on the fact that the centre of the continent rises high above sea-level (W. Meinardus). Others, however, are of the opinion that a vast ice region like the Antarctic should create its own system of anticyclone movement. This theory is proved by the fact that in the Northern Hemisphere there were anticyclones in the glacial epochs. In 1915, the American glaciologist W. Hobbs suggested a hypothesis of glacial anticyclones. His views regarding the Antarctic regions are shared by Kidson, Rubin and Tauber. The American expedition of 1946-47 found that there were two anticyclonic nuclei on the continent, while H. Lamb (1948-52) thinks there are even three. Tauber writes that the division of the Antarctic anticyclone can take place temporarily as it weakens. The centre of the anticyclone, he says, is in 80°-85°S., 70°-100°E.

Observing the smoking Mount Erebus, the Scott expedition came to the conclusion that there was a double-layer circulation of air over Antarctica. The lower layer was the cold continental air moving seaward and the upper was the warm sea air moving inland. Radiosondes established that such circulation brought about a considerable inversion of temperature at the boundary between two air masses. In the coastal areas, the height of the inversion layer is 1,000-2,000 metres, with the northwest air drift dominating above that, while over the continent it is between 200 and 300 metres.

Thus, at the height of between 1,000 and 5,000 metres above sea-level the Antarctic anticyclone gives way to a stable high-altitude cyclone. The boundary between the two baric systems is not permanent. In winter, it is assumed, it is at a greater altitude than in summer.

The study of air circulation over Antarctica is absolutely necessary for the determination of the thickness of the continental ice-sheet and analysis of its development, past and present. The dry anticyclonic regime is not conducive to the development of glaciers and many authorities claim that

they get their nourishment thanks to the cyclones which cause heavy precipitation, especially in the mountainous regions on the coast. Lamb, for one, considers it quite possible that the cyclones cross the continent. But although a number of cyclones were recorded passing inland, very little is as yet known of their character and significance. Tauber considers that the instability of weather, as recorded also in the interior where snowfalls alternate with fine weather, is due to the disturbance of anticyclonic circulation.

New data on the nourishment of the continental ice-sheet by precipitation were obtained by the Soviet expedition. Proceeding from the data collected at Mirny, Tauber concluded that the level of condensation in the sea air mass lay in the stratum at 200 to 1,500 metres and that the zone with the greatest precipitation should be five to 150 kilometres from the coast. In the more elevated parts of the continent precipitation should be in the form of hoar-frost.

Observations made at the Pionerskaya Station 2,700 metres above sea-level, 375 kilometres from the coast, surprised the explorers by revealing considerable humidity in this area.

A. M. Gusev, who is in charge of this station, attributes this to the fact that the relatively warm and humid air masses moving inland very often descend to the surface of the ice-sheet as a result of the wave developments at the boundary dividing them from the low-altitude anticyclone.

At the international Antarctic conference in Paris in May 1957, Gusev said that, in his view, the atmospheric circulation in the Antarctic was one of the most powerful in the world and determined the climate of a big part of the Southern Hemisphere.

The circulation is the result of the thermal interaction of the atmosphere on the surface of the continent and that of the surrounding oceans. The latitudinal temperature gradient is due to the difference of temperature of the open

seas in the north and of the ice-sheet in the south. Thus. the ocean belt around the continent reveals the contrast between the thermal fields particularly sharply in winter.

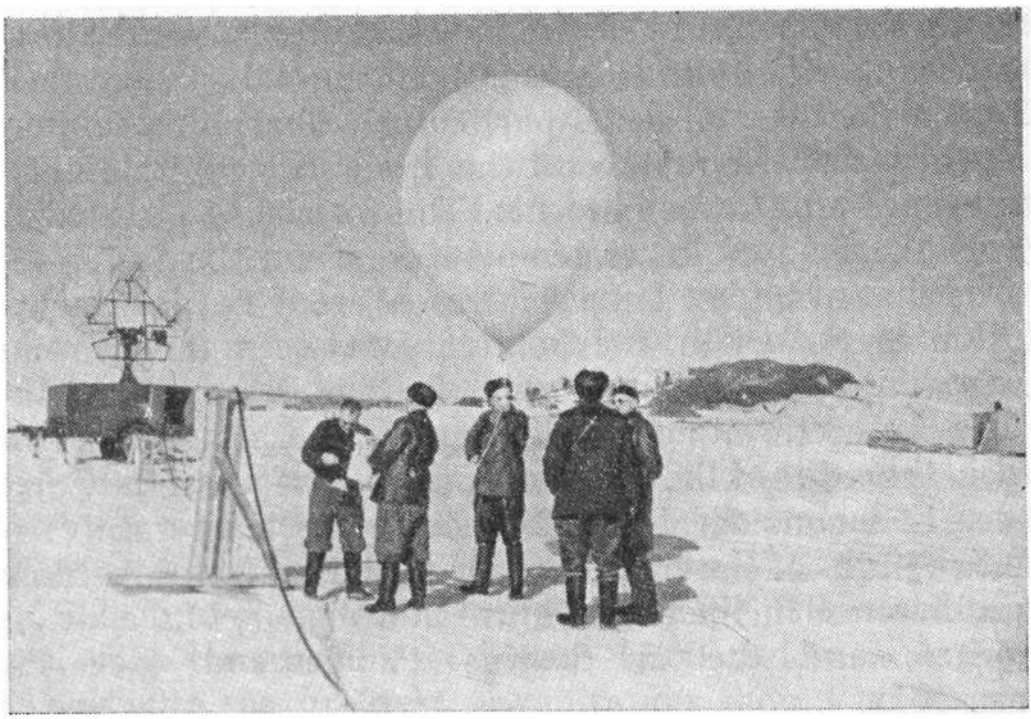
A characteristic feature of the circulation is its division into upper and lower currents. The former is directed towards the field of lower temperatures and the latter—towards that of higher temperatures. Were it not for the revolution of the earth, the boundary between the two currents would be horizontal; as it is, it is dome-shaped.

The Antarctic atmospheric front is the section line between the edge of the air dome and the surface of the Earth. There is a considerable difference in the temperatures on the two sides of the front. Nearer to the centre of the dome the difference in the temperature and density of the air disappears, and the air begins to descend (see Fig. on p. 161).

Gusev believes, as his chart shows, that the climate of the area is determined by the circulation and that the weather is determined by the wave between the two currents. They are caused by the differences in the velocity, direction and density of the currents. The most probable type of wave, he says, is the standing wave whose main line passes in the centre of the dome's radiuses. With such vacillations, the surface of the dome will alternately flatten out or swell up, and the front will move on the surface of the Earth. Standing waves usually last from 15 to 20 hours. Slower vacillations on the surface of the boundary, leading to lengthy movements of the front, may be traced to the seasonal changes in the velocities of the upper and lower currents.

Apart from standing waves there may form on the surface of the dome mobile waves similar to the wind waves on the surface of the water. The parameters and velocity of these waves vary considerably.

The difference in the temperature of the two air masses, Soviet observations reveal, amounts to 15°-20° C. The surface of the boundary between the sea and continental air



Establishing radiosondes in the Mirny area (Soviet Antarctic expedition, 1956)

was reconnoitred from the air from the Mirny Observatory to the magnetic pole in 76°30′S. Observations made from the *Ob* showed that this boundary stretches far out into the sea. Its altitude in the area of the Pionerskaya Station is about 500 metres, and between 200 and 300 metres in the area of the Vostok-I Station.

The descent of the sea air is accompanied by a sharp rise in temperature and heavy precipitation. At the Pionerskaya the precipitation figure for 125 days (1956) was 72 millimetres.

Observations at Mirny and Pionerskaya reveal seasonal fluctuations in the rise of temperature, and they are particularly sharp in summer.

The average annual atmospheric pressure at Mirny (1956-57) was about 987 millibars. At the Komsomolskaya Station (74°8′S., 97°17′E.), situated 860 kilometres inland at 3,500 metres above sea-level, the pressure, according to

observations made from March 7 to 25, 1957, was about 640 millibars, and that would make it 910 millibars at the sea-level. This corresponds to a strong cyclone. Thus, the baric field of the continent possesses a more complicated structure and regime than it had been hitherto assumed.

To some extent, cyclonic processes in summer are apparently influenced by snow-free sectors, the oases. In the inter-glacial periods, these sectors obviously played a particularly important role in the destruction of the continental anticyclone.

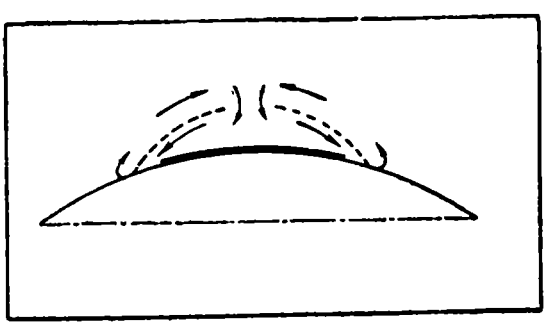
At any rate, the fate of the ice cover of the Southern Hemisphere and the circulation of air are closely interconnected, and one may well agree with Kidson that the study of the Antarctic region is of vast importance for a proper understanding of the periodicity of the world weather and the drawing up of long-term synoptic charts (E. Kidson, *Meteorology,* Russ. ed., Moscow, 1937). It may be added that the understanding of the meteorological processes in this region is also essential for whaling and sealing in the Southern Ocean.

A major contribution towards this has been made by Tauber, who has worked out the basic types of synoptic processes in the Antarctic. It is quite understandable, however, that the results are not exhaustive and the theme presents wide possibilities for further study.

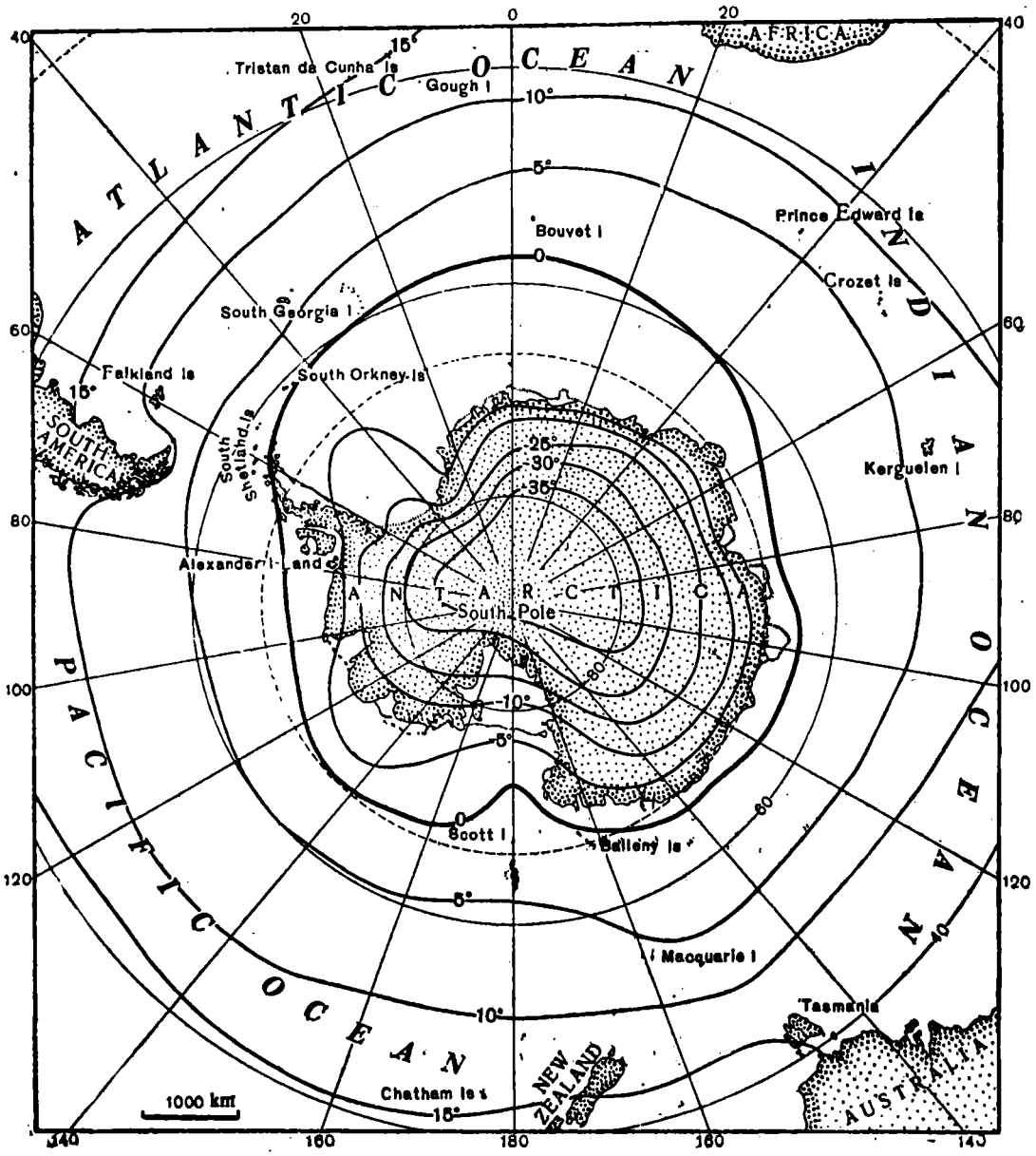
CLIMATE IN ANTARCTICA

Antarctica's climate is divided into *oceanic* and *continental.* The oceanic polar climate predominates in the water belt around the continent.

In the Antarctic waters, the climate is cloudy, windy and cold. Its characteristic traits are low



Scheme showing atmospheric circulation over Antarctica (after A. M. Gusev)



Isotherms in January, the warmest month in Antarctica, not brought to sea-level (after H. P. Kosack, 1954, with modifications)

clouds, frequent fogs, precipitation of snow throughout the year, low temperature, and gales. The weather is worst in spring. Observations carried out by the *Slava* flotilla in the Antlantic sector in November 1954 showed that there were 15 days of storm (50 per cent), 17 days of fog (57 per cent) and 15 days of snowfall (50 per cent). Average cloudiness was 97 per cent. Only on two occasions did the sun shine completely unobstructed by clouds. The average temperature of the air and water was minus 0.1° C. The *Slava* encountered about 1,000 icebergs, and there was not one day of calm.

The most typical trait of the Antarctic's climate is its constantly low temperature of the air in summer, which is due to heavy cloudiness.

In the open ocean, in lat. 55°S., cloudiness in spring and summer reaches 90 per cent[1] on South Georgia and Kerguelen islands—70 per cent and on the Antarctic coast —50 to 70 per cent. It is least in May-September and heaviest in November-December. Only once in twelve months did the author record a temperature of the air upwards of 5° C. (5.3°) in the open ocean. And yet farther south, on the continental coast, where the average temperature is lower, there are warm, sunny days in summer. In the area of the Mirny Observatory (66°33.6′S.), average cloudiness in November was 77 per cent and in May—51 per cent (A. Scholes. *Antarctic Air Exploration*, "*Flight*", Vol. 66, No. 2384, October 1955, p. 93). The sun sometimes shines for days in summer and the temperature of the air rises to 8°C. According to the Soviet expedition's report, sun radiation raises the temperature on the dark rock face to 30° C. Thus, the cloudy climate of the Antarctic Ocean differs sharply not only from the sunny latitudes to the north, but also from the less overclouded shores of the continent. The beclouded Antarctic Ocean might well have been called "Cloudy Ocean."

One of the gloomiest descriptions of this ocean has been

[1] According to *Slava* observations in 1954-55—95 per cent.

given by the British explorer Bennett, who writes that lengthy periods of bad weather in the Antarctic are the characteristic feature. Leaden clouds cover the sky and blot out the sun for days and weeks. Darkness and low atmospheric pressure are enough to break even a strong

A tractor-drawn sledge party (Soviet Antarctic expedition, 1956)

man, he adds. The picture is the same wherever one looks —dark skies, black waters, sparkling ice massifs covered with ghostly white sheets.

There are frequent fogs in all seasons of the year. The number of foggy days varies from 17 a year in Marguerite Bay to 246 in the Bellingshausen Sea. On the South Polar Plateau the fogs are less frequent than on the islands and the coast, where the influence of the ocean is much greater.

The temperatures on the islands in the north and south of the Antarctic region vary considerably. Average temperatures in lat. 50°S. fluctuate in summer from about 4°C. to 7° C. and in winter from 1° C. to minus 2° C. Farther

Table 6

Number of Foggy Days

Observation station	Number of years of observation	Months											
		1	2	3	4	5	6	7	8	9	10	11	12
S. Georgia, Cumberland Bay .	19	4	4	5	5	5	3	4	4	4	3	3	4
S. Orkneys, Laurie I.[1]	7-8	16	12	16	13	18	18	19	20	18	17	16	13
Snow Hill I. . .	1	16	14	4	9	11	11	8	9	7	9	8	12
Graham Land, Marguerite Bay	1	2	1	2	1	1	2	0	3	1	1	0	2
Bellingshausen Sea	1	17	23	14	26	27	28	17	25	14	23	18	13
Palmer Archipelago	1	2	0	4	3	2	1	5	5	7	0	2	—
Pettermann I. . .	1	5	6	10	13	20	13	23	25	25	24	20	—
Bay of Whales .	3	2	1	2	6	2	2	3	4	6	5	4	6

south they drop rapidly—in summer from 1.7° C. to minus 3.3° C., in winter from minus 9.4° C. to minus 23.9° C.

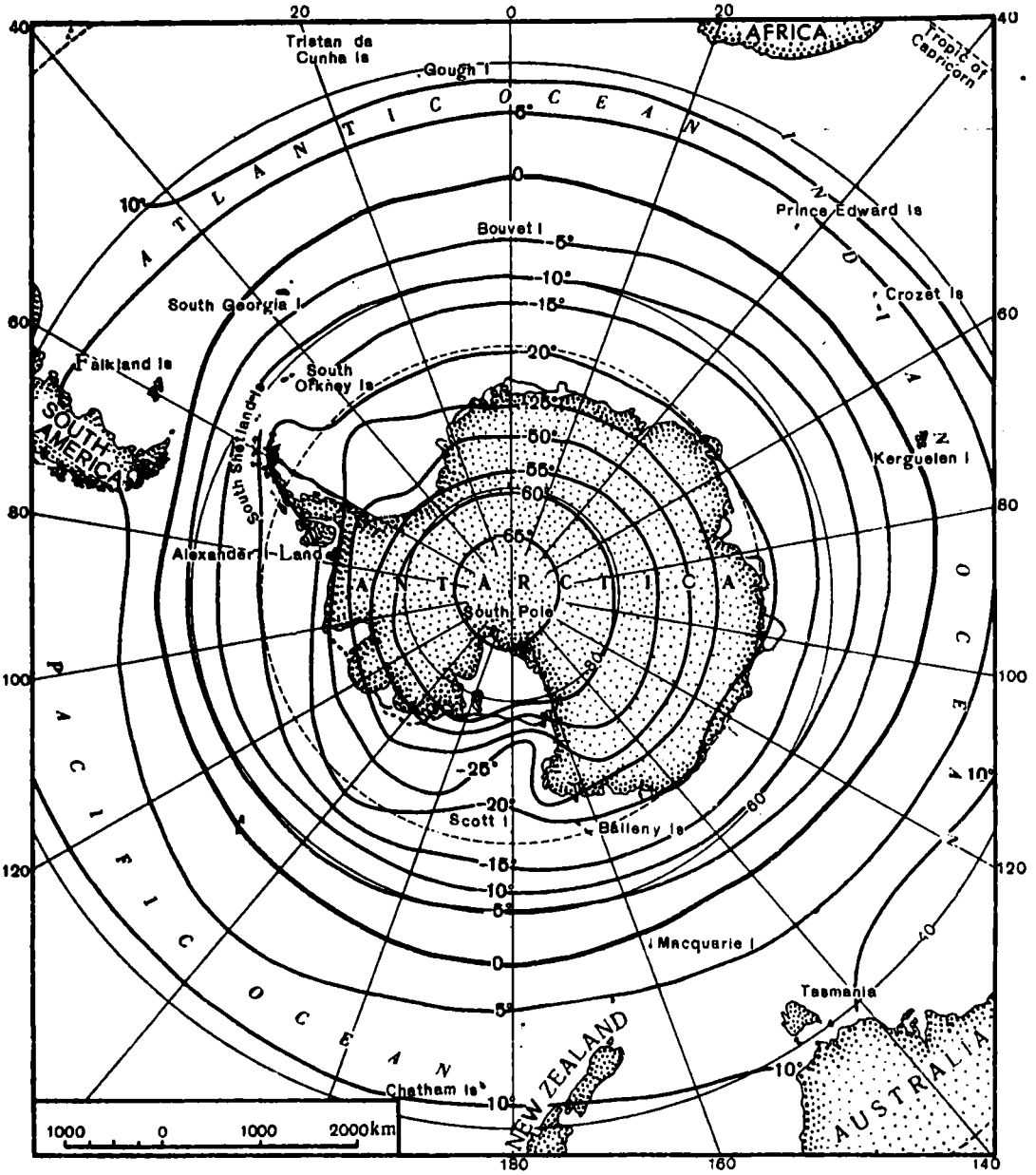
The average monthly temperature of the air in winter is minus 20° C. on some coasts and minus 40° C. on others.

At Mirny in August 1956 it was minus 20.9°C., with the absolute minimum of minus 40° C. August was also the coldest month at the Pionerskaya Station, with the mercury dropping to minus 52°C., with the minimum of minus 64° in July and minus 66.8°C. in August. For one whole week in August the temperature was below minus 60°C.

At Vostok-I Station, the temperature in May 1957 was minus 52.7°C., the lowest being on the 9th—minus 70.1°C. On that day the temperature was minus 68°C. at 3 a.m., minus 66°C. at 9 a.m. and minus 62°C. at 3 p.m. The maximum force of the wind in May was 16-18 metres per second at a temperature of minus 55-57° C.

On May 11, 1957, the U.S. Antarctic expedition recorded minus 73.5° C. (*New York Times*, May 26, 1957). And the

[1] Number of foggy or hazy days.



Isotherms in July, the coldest month in Antarctica, not brought to sea-level (after H. P. Kosack, 1954, with modifications)

lowest temperature in the world—minus 86.7° C.—was registered in the Sovetskaya Station area on August 10, 1958.

Soviet Antarctic explorers believe that the average temperature in the centre of the continent during the coldest months is minus 60-65°C. and the minimum—minus 70-75°C.

In summer, the maximum average monthly temperature on the coasts is 0°C. and minus 10°C., in the interior—minus 20° C., minus 35° C. At Mirny, it was minus 0.7° C. and at Pionerskaya—minus 20.9° C.

Rusin has calculated that average sun radiation at Mirny in January amounts to about 15 big calories, which is equivalent to a total sun warmth for the summer of 40-45 calories. The summer albedo is about 75 per cent of average radiation. As a result of major reflection and heightened effective radiation the radiation balance in summer apparently does not exceed 10-15 per cent of average radiation, which is between four and five times less than in the same latitudes of the Northern Hemisphere. In winter radiation is equivalent to 4-6 large calories.

On clear days the temperature at Mirny fluctuates by 13-15 degrees C.

The annual amplitude of the mean monthly temperatures in Antarctica is apparently almost one and a half times less than that in the Arctic Ocean. For that reason. Alisov says the amplitude of temperatures in the polar regions cannot be taken to indicate that the climate there is continental.

	Central Antarctic	Central Arctic
Average temperature of the warmest month	—35°	0°
Average temperature of the coldest month	—65°	—40°
Annual amplitude	30°	40°

The difference in average temperatures in various parts of the Antarctic is shown in Table 7.

With the exception of the coastal areas, the climate in the Antarctic is continental polar, characterized by negative temperatures in summer and winter and by slight precipitation—between 300 and 400 millimetres a year on the coast and, according to certain authorities, only 5 milli-

Table 7

Average Monthly Temperatures (Centigrade)

Observation station	No. of years of observation	Months											
		1	2	3	4	5	6	7	8	9	10	11	12
S. Georgia, Cumberland Bay . . .	22	5.0	5.6	4.4	2.2	0	−1.7	1.7	−1.7	0.6	1.7	2.8	3.9
Kerguelen I. . . .	1	6.7	7.2	3.9	3.9	1.7	2.8	0.6	1.1	0.6	1 1	3 9	5.0
S. Orkneys, Laurie I.	21	0	0.6	−0.6	−2.8	−7.2	−9.4	−10.6	−9.4	−6.7	−3.9	−2.2	−0.6
Snow Hill I. . . .	1	−1.1	−3.3	−10.6	−13.9	−18.3	−20.0	−20.6	−18.9	−15.6	−9.4	−8.3	−2.2
Graham Land, Marguerite Bay . . .	1	1.1	−0.6	−1.1	−3.9	−13.3	−17.8	−14.4	−14.4	−6.7	−2.2	0.6	1.7
Bellingshausen Sea	1	−1.1	−1.1	−8.9	−11.7	−6.7	−15.6	−23.9	−11.1	−18 9	−7.8	−6.7	−2.2
Queen Mary Land, Gauss Mountain .	1	−1.1	−3.3	−8.3	−15.6	−13.9	−17.8	−18.3	−21.7	−17.8	−12.8	−6.7	−1.1
King George V Land, Cape Denison	1	−1.1	−3.9	−10.0	−16.7	−16.7	−18.9	−20.0	−16.7	−17.2	−16.1	−8.3	−2.2
Ross Sea, McMurdo S.	5	−4.4	−8.9	−15.6	−22.8	−23.9	−24.4	−26.1	−26.1	−24.4	−18 9	−10.0	−3.9
Bay of Whales . . (78°40′S., 154°W.)	1	−9.1	−15.6	−21.7	−27.8	−35.6	−34.4	−36.7	−42.2	−37.2	−24.4	−15.6	−6.7

metres in the area of the Pole (P. A. Shumsky, *Foundations of Structural Glaciology,* Moscow, 1955). Average precipitation on the continent, computed on the basis of the humidity content of the air, is close to 90 millimetres a year. It is considerably more on the Antarctic islands—1,301 millimetres on South Georgia, 850 millimetres on Kerguelen Island and 403 millimetres on the South Orkneys.

Table 8

Days with Precipitation

Observation stations	No. of years of observation	Months											
		1	2	3	4	5	6	7	8	9	10	11	12
S. Georgia, Cumberland Bay	19	16	16	18	19	19	16	17	17	15	13	16	15
Kerguelen I.	1	23	21	27	18	27	27	26	26	22	29	25	21
S. Orkneys, Laurie I.	8	16	12	20	20	20	19	22	21	19	18	19	15
Snow Hill I.	1	23	13	11	13	11	7	9	7	11	13	24	13
Pettermann I., Port Circonsion	1	13	19	25	20	27	18	25	24	23	25	18	—
Bellingshausen Sea	1	19	22	13	22	30	24	14	26	19	25	25	18

Precipitation grows less farther south, and it is mostly in the form of snow, which falls even in the warm months. The snow cover in Antarctica is uneven and there are high snowdrifts. Very often instruments are covered with rime and ice crystals, making survey difficult. The relative humidity of the air at Mirny averages 67 per cent a year.

The winds are most frequent and strongest on the boundaries of the Antarctic, between 40° and 55°S. Farther south their force diminishes, but in the higher latitudes the winds are considerably colder. The names given by navigators to various latitudes of the Antarctic—"Roaring Forties," "Furious Fifties" and "Screaming Sixties"—reflect both the winds and the temperatures in these parts.

A month without a storm and a year without a hurricane in any spot of the Antarctic beyond 50°S are consid-

ered exceptional. Nevertheless, there have been instances of ships crossing the ocean without running into a single storm. Very often the wind is force 7 for weeks and months. Winter months are stormiest.

Between 50° and 55°S., wind force averages 6-7. There are between one and three calm days in a year. The wind is usually west or northwest. The latter is observed particularly in summer. The periodicity of the weather is reflected best by the uninterrupted chain of cyclones. In one week the wind changes its direction several times from northwest to southwest. In the first case, the weather is damp and foggy, in the second—clear and squally. Northwesterly winds sometimes blow for days, the southwesterly seldom last two days. As a rule, cloudiness increases in the first 24 hours and the appearance of a halo around the moon and the sun is a sign of rapid deterioration of the weather.

Blizzard at Mirny (Soviet Antarctic expedition, 1956)

Westerly winds predominate between 55° and 60°S., but the percentage of southwesterly and northwesterly winds increases markedly. The average wind force is 5-6. There are between two and five calm days in a year.

Between 60° and 65°S. westerly and easterly winds are equally frequent. There are between two and seven days of storm in a month and one or two days of calm. Periods of lull sometimes last three or four weeks.

The region south of 65°S., off Antarctica's elevated ice-sheet whence descend the cold air masses, is subject to sudden storms of exceptional severity and snow squalls. The wind here is mainly southeast. The southeasterly wind blows on between 53 and 83 per cent of days on Queen Mary Land and between 52 and 72 per cent on the western shores of the Ross Sea. Wind force fluctuates sharply from place to place. The windiest spot is the coast of Adélie Land, where storms rage up to 310 days in a year. The average annual speed of the wind is 19.2 metres per second in July and 23.6 metres per second in May. On these occasions the average monthly temperature of the air is minus 23°C. and sometimes as low as minus 33°C. At times wind velocity is 55 metres per second, with gusts of 92.6 metres per second. Winds like this raise snow columns up to 120 metres in height and 90 metres in diameter, blow away things weighing between 150 and 200 kilogrammes, polish metal articles, tear rigging and fill radiators and cowls with snow.

The speed of the wind recorded at Mirny on the shore of the Davis Sea exceeded 46 metres per second. There is very little wind—gales have been recorded only on 2 per cent of days—in the area of the U.S. Antarctic station in the Bay of Whales. The average annual speed was slightly below 40 feet per second. There were 211 days of storm between March and the end of November 1956. Between 40 and 60 per cent of these storms were due to winds blowing from the ice sheet. The borderline of these seaward winds passes in the area of Mirny between 10 and 12 metres from

the shore. On the shelf 14 kilometres from the shore their force drops to 0.1.

The Soviet expedition calculated the speed of surface winds and found that in summer they blow strongest after midnight. Calm sets in at noon. In winter, surface winds blow almost non-stop the whole of the day, weakening somewhat towards noon. They are strongest in August, that is, in the coldest month of the year.

The severity of the climate is often calculated on the basis of Bodeman's formula:

$$C = (1 - 0.004t) \cdot (1 + 0.272v),$$

Were t is the temperature of the air in C.,

and v is wind velocity in metres per second.

Coastal observations in Antarctica in 1953 showed that average severity was equivalent to 4.2. At Mirny, in 1956-57, it was 4.4 (average annual) and 4.7 (winter).

The average annual temperature of the air at Mirny is minus 10.2°C.

SOME PROBLEMS OF PALEOGEOGRAPHY

We now have sufficient data to show that Antarctica's glacial climate did not always prevail, that it possibly characterized only a brief period in the geological history of the continent. That is evidenced by the fact that fossils of warmth-loving plants have been discovered not only near the shores, but in the interior as well.

Coal seams and subtropical fern fossils of the Upper Carboniferous times were first discovered by the Shackleton and Scott expeditions in the upper reaches of the Beardmore Glacier in 85°S. The analysis of schists on Victoria Land produced evidence that in the Pre-Cambrian period the climate there was dry and cold, possibly polar in character. Erratics of fossiliferous limestone imply warm or temperate conditions which, as far as one can judge from data available, continued uninterrupted until the Quat-

ernary period. The mysterious thing, Rhodes W. Fairbridge writes, is the absence of glacial evidence in rocks of Permian age, which was a time that experienced intense glacierization in all other parts of the Southern Hemisphere—in Africa, India, Australia and partly New Zealand. The warm period that began in the Paleozoic period is proved not only by the fossils of Cambrian limestone, but also by the formation of limestones which would have been impossible in the cold polar waters, undersaturated as they are in calcium carbonate.

The late Paleozoic periods are marked by the widespread development of the Beacon Sandstones, which Fairbridge describes as sandstones with wind-rounded grains. Their character shows that the conditions then were not tropical, that they were extremely long conditions of aridity, interrupted by brief periods of desert flooding and some amelioration of climate that allowed the coal flora to grow (*The Antarctic Today,* p. 89).

Rocks of Mesozoic age have been found only in the western part of the continent. Jurassic flora in Graham Land is warm to tropical, with close affinities to Africa and India, while in Cretaceous times there is evidence from Graham Land of coral fauna of typical Indo-Pacific character. As is known, coral organisms in these regions do not develop if the average annual temperature of the water is below 20.5° C., and below 19° C. or 18° C. in winter.

In the first half of the Tertiary period (Eocene and Oligocene) there was, in West Antarctica, flora of warm character, including laurel and fig. As Fairbridge points out (*The Antarctic Today,* p. 90), these Tertiary and Cretaceous beds are rich in glauconite, the formation of which mineral is incompatible with rapid polar sedimentation. It is only with the Quaternary that truly continental glacial material appears, as far as it is known now.

An idea about Antarctica's paleogeography may be obtained from Table 9 below, which, by way of comparison, gives analogical data on India:

Table 9

Age	Period	Beginning of the period (millions years ago)	Duration of period in millions of years	Climatic conditions	
				Antarctica	India
Cainozoic	Quaternary	1	1	Glacial climate	Tropical climate
	Tertiary	56	55	Flowering plants, figs, laurels	Hot climate
Mesozoic	Cretaceous	116	60	Coral fauna of warm character	Wet climate, allowing coal flora to grow
	Jurassic	141	25	Warm climate, flora from warm to tropical	Arid hot climate with regional development of coal flora
	Trias	165	25	Sand deserts and coal flora	
Palaezoic	Permian	205	40		
	Carboniferous	280	75		Glacial climate
	Devon	320	40	Warm or temperate conditions	Coral fauna of warm character
	Silurian	405	85		
	Cambrian	495	90	Arid cold climate	Glaciation
	Pre-Cambrian	3,000-5,000 million years			

It should be borne in mind that the data contained in the table have been obtained in the course of investigations at a few points, situated far from one another in the outlying parts of the continent, and for that reason they cannot be regarded as complete.

An explanation of changes in climate (through polar migration and "continental drift") is given in the works of W. Köppen and A. Wegner, published in 1912, 1924, 1936 and 1940.

This theory, seemingly solving the paleogeographical mystery of Antarctica, has failed to explain the Quaternary glacierization of the Northern Hemisphere. The Köppen-Wegner theory was built on the hypothesis that in the Tertiary period the North Pole migrated from the Pacific Ocean to the Arctic Ocean by way of Bering Strait. Later reconstruction of the Tertiary nature in Alaska showed that the Pole had never been on her territory. After that the ring of climatic belts was closed, and the last "gates" to the Antarctic were shut. According to Flint (1947), climatic belts in the Quaternary period displaced parallel to themselves along lines radiating from the Arctic basin.

Moreover, the drift theory was criticized from the geophysical point of view.

Thus, the warm climates of the Antarctic lands may be explained by their polar position. The conditions of the problem will change considerably if one proceeds from the continental or island hypothesis of the Antarctic structure. In the latter case, solution will be easier.

Gaining popularity are the so-called solar-topographical glacial hypotheses, whose authors attribute glacial developments to the changes in the sun radiation upon the earth and to changes in the earth's relief. Among the Russian exponents of these hypotheses are A. I. Voeikov, I. D. Lukashevich, I. P. Gerasimov, K. K. Markov and M. S. Eigenson.

One of the most detailed and up-to-date definitions of the solar-topographical theory was given by Flint in 1947.

The American scientist considers that one of the causes for the appearance of glacial periods was the formation of mighty mountain ranges of planetary scale. The cause of Quaternary glacierization was the formation of mountains in the Neocene, in the main phase of the Alpine folded belts. In the latter half of the Cainozoic Age, the average level of the continents, Flint claims, increased 2.5 times.

The formation of new mountains, however, could not be the only cause for the appearance of glacial periods, the American scientist admits, for the glacial period then would have continued non-stop from the Pleistocene to the present day. And so another argument is adduced to explain glacierization—fluctuations in sun radiation. Thus, glacierization is caused by two factors—mountain formation and decrease in solar heat. The latter is probably the chief cause inasmuch as the interglacial periods are not linked with tectonic movements.

But, as Flint admits once again, there is nothing that can be said of this chief cause now with the exception that it probably did exist.

In brief, the cause of glacierization actually remains a mystery.

The "hypothesis of oceanic control" suggested by Stokes in 1955 gives an entirely different solution for the problem of interglacial periods. Briefly, his theory assumes that sun radiation upon the earth remains invariably the same. The oceans tend to preserve thermal equilibrium with solar heat. This equilibrium prevailed in the pre-glacial epoch, when the average temperature of the water was 10° C. above the present-day temperature, and was disturbed by intense formation of mountains and elevation of continents. The formation of late Tertiary Alpine folded belts ushered in the initial phase of ice accumulation which, in its turn, started off the chain of Quaternary phenomena.

In this period the cold water of the glaciers flowed into the rivers and cooled the surface layers of oceans. Next came the formation of sea-ice and the sinking of cold

water in the polar regions. The temperature gradually dropped in all the oceans.

Climatic consequences of this process are most varied, but the most important phenomenon is the diminution of evaporation, which is followed by gradual and slow decrease in precipitation all over the Earth. And, as a result, glaciers progressively decrease in size and eventually disappear.

Due to the specific properties of water (high thermal capacity and temperature of ice formation) and to the huge volume of ocean waters, changes in temperature at sea and on land do not coincide in time.

While the ocean remains cold as a consequence of glacial influence, the Earth receives and preserves more warmth. The rivers become warmer than they were at the time when glacial waters flowed into them. The volume of water over the shallow continental shelves increases, the icebergs and, eventually, sea-ice disappear, the influence of albedo grows less and the ocean becomes warmer. After a certain period of time, measured by thousands of years, evaporation and precipitation increase once again and the revival of glaciers becomes inevitable, provided there exist the topographical factors favouring the formation of snow and floes.

This process repeats periodically and lasts until topography becomes sufficiently low as a result of erosion or isostatic movements. When the relief has become lower, it will rain where it used to snow, and no ice will form in sufficient quantities to start a new glacial cycle. The temperatures in the oceans will again be governed by solar heat. Thus, the ultimate conditions of glacierization, like its beginning, are determined by topographical conditions which are governed by the integration of the orogenic forces inside the earth and the denudation processes on its surface.

To predict present-day developments it is necessary to know whether or not the culminative point of the freezing

of oceans by glaciers has been passed. It is evident that the most important data regarding the dynamics of the interaction of continental ice and the oceans will be obtained in the Antarctic water belt.

The paleogeography of Antarctica is of vast significance for the study of climatic changes in the world.

FAUNA

WHALING

It is very difficult to trace the history of whaling. The people inhabiting the northeastern parts of our country began hunting whales in times immemorial. First evidence of whaling in Western Europe, in the Bay of Biscay, dates back to the 10th century.

At first, hunting was conducted from rowboats and shallow vessels, with hand harpoons and spears. For many centuries man hunted only for Right and Sperm Whales because of their relatively low speed and the buoyancy of their bodies after death.

That went on until 1868, when a Norwegian whaler named Svend Foyn perfected explosive harpoons and pumps were installed to inflate whales' bodies. The rowboat gave way to the schooner which was fast enough to catch Rorquals.

Another noteworthy event in the history of whaling was Carl Larsen's invention of a stern slipway making it possible to haul the whale aboard for flenching. Before the Norwegian's invention, the job of flenching whales had to be done at sea and was naturally impossible in choppy waters. For that reason it was done usually near the coast or at least under the cover of ice.

Regular whaling in the Antarctic dates back to 1904-05, but until 1924 it was almost exclusively restricted to the South Georgia and South Shetland regions. From time to

time whalers appeared off the South Orkneys and Crozets, that is, in places where a century earlier sealers had destroyed Fur Seal rookeries.

The following is a brief résumé of the history of whaling, now concentrated 90 per cent in the Antarctic.

In the 14th century the Biscayan whalers began hunting Right Whales in the North Atlantic. They were emulated by the Dutch and the British in the 16th century. Towards the end of the 17th century the former were capturing up to 1,000 whales a year and held first place up to the 18th century.

Whale oil was used mainly for lamps, as well as for tanning purposes and as a lubricant.

Early in the 18th century whale-hunting was joined in by the North-American colonists, who discovered that the spermaceti (a white, waxy substance obtained from the head of the Sperm Whale) was an excellent raw material for candles. The demand for the spermaceti and its price soon rose to almost double that of oil. The result was rapid development of whaling and by the turn of the 19th century whaling schooners, especially American, were plying the Pacific from the northern to southern latitudes, hunting in the immediate approaches to Antarctica—off the Falkland, Kerguelen and Crozet islands.

The once big stocks of the Southern Right (Cape) Whales off South Africa, New Zealand, Australia and Tasmania were being reduced at the rate of 14,000 head per annum, with the result that they became practically non-existent in the 19th century.

The discovery of petroleum in 1859, which replaced whale oil as an illuminant and lubricant, dealt the whaling industry a telling blow. Oil and spermaceti prices began to drop precipitously. In the 1860's, the oil obtained from one Southern Right Whale brought about $5,000, in the 1870's—less than half of that. The price of spermaceti dropped from $2,000 per whale to $1,000 and less (*The Antarctic Today*, p. 154).

In the pre-plastics era the baleen of the Right Whale used to bring the hunter as much as $6,000 (it fetched as much as $4 a pound in San Francisco in 1897). This stiff, springy substance was used for making wheel hoops and sleigh runners, corsets, plumes, watch springs and many other articles. The hunt for profits greatly depleted the stocks of these whales.

Repeated attempts to hunt whales in the Antarctic were made at the turn of the 19th century. In 1799-1800, the British sealer *Hillsborough* hunted whales off Kerguelen Island, which lies on the borderline of the Southern Ocean. In 1808, the British whalers *Swan* and *Otter* rediscovered Bouvet Island. An unsuccessful attempt to hunt whales in the Antarctic was made by Captain Biscoe of the sealer *Tula*. In 1850, British whalers sailing in the schooner *Brisk* approached the Balleny Islands.

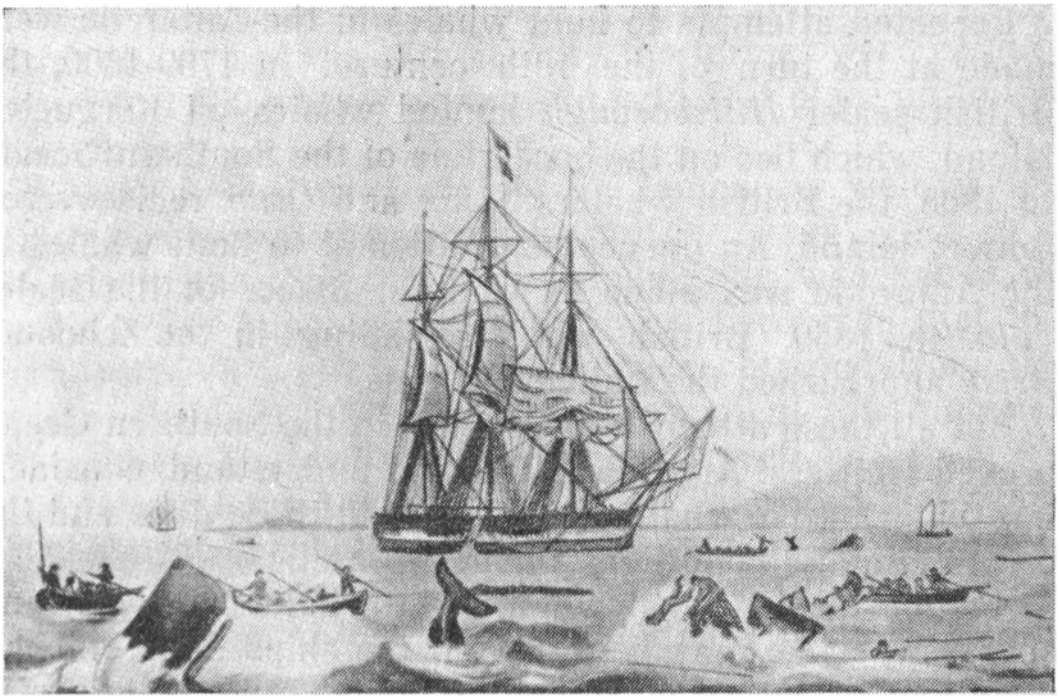
But all these attempts at whaling in the Southern Ocean proved fruitless. And that is easy to understand, considering the primitive whaling techniques in those days and the severe climatic conditions in the Antarctic.

A good idea of what whaling with hand harpoons and spears was like may be got from the ships' logs and descriptions of those days of sailing boats. There is the story, for instance, of a hunt from two whaleboats of a Norwegian vessel. The whalers hit a whale with four harpoons, but the wounded animal smashed one of the boats and got away.

On another occasion three boats pursued a harpooned whale only to be overturned and smashed. In 1854, a female Right Whale, infuriated when her calf was killed, destroyed three boats. Many a whaler met his death hunting Sperm Whales. There are stories of wounded Sperm Whales destroying not only little boats, but whole vessels by battering them, as was the case, for instance, with the sailers *Essex* (1820) and *Alexander* (1851).

Sometimes even modern whaling ships come out losers from encounters with Sperm Whales. Wounded, the ag-

gressive animal very often does a loop in the water and guided by the hum of the screw propeller, rushes at the ship. That is why the engine is switched off or the vessel is steered away the moment a harpoon is fired. And even with such precautions damage is possible. In February 1954, for instance, a wounded Sperm Whale smashed a



Hunting Sperm Whales in the early 19th century (E. W. Hunter Christie, 1951)

blade of the screw propeller of the *Slava-6* and the vessel had to be towed to Capetown for repairs. That same year damage was also suffered by two foreign whalers, the *Balaena* and the *William Barents*.

Whale-hunting in sailing boats in the Antarctic was especially perilous, for the extremely low temperature of the water was more than some of the men from the overturned and smashed boats could stand.

It was only in 1893 that the first whale was killed south of 55°S. (*Antarctic Sailing Directions*, Moscow, 1948)

Regular whaling, however, was started only in 1904, when an Argentine firm set up the first coastal whaling station, manned mostly by Norwegians, on South Georgia.

The catch in that first season of 1904-05 amounted to 195 whales and the news of this success brought a great many whalers to the Antarctic. The first Norwegian factory-ship appeared in these waters a year later. After that the industry developed rapidly, with Chile joining in in 1906 and Britain in the following season. By 1912, Norway had 37 factory-ships and 27 coastal stations.

Flenching was still being done at sea and the whalers continued hunting near the islands, going chiefly after Humpbacks which often approach the shores. Of the 10,000 whales taken in 1910-11, 8,000 were Humpbacks. By then the Antarctic was accounting for upwards of 50 per cent of the world whale catch.

In the 1923-24 season Larsen discovered hosts of whales in the Ross Sea. The invention of the slipway permitted whalers to sail much farther without having to look for shelter for flenching operations, though the only countries to do that before 1931 were Norway and Britain.

More and more countries joined the industry—the United States and Denmark in 1930-31, when the Antarctic was already accounting for 97 per cent of all the whale oil in the world, and Japan, Panama, South Africa and Germany in 1934-37.

Whale oil production and prices in those years were determined by market demands and underwent considerable fluctuations.

In 1920, a ton of oil cost about $360, in 1924—$152, in 1931—$40, in 1934—$51 and in 1946—$147.

The maximum prewar oil output figures were 601,391 tons (in 1930-31, when 40,201 whales were killed) and 556,722 tons (in 1937-38, when 46,039 whales were killed).

These record figures have yet to be equalled.

Whaling was almost completely abandoned during World War II. The whaling fleet suffered serious damage:

28 out of the 41 factory-ships were lost, four converted to other uses, and only nine remained intact (five Norwegian, three German and one British (*The Antarctic Today*, p. 163).

The only country to engage in whaling in 1941-42 was Japan. There were no whale fleets in the Antarctic in the 1942-43 season and hunting was restricted to one coastal station. Towards the end of 1943 a Norwegian flotilla reappeared in the Southern Ocean. In 1944-45, there were one flotilla and one coastal station; in the following season (1945-46) the number of flotillas increased to nine. The first Soviet whaling flotilla in the Antarctic was the *Slava* (1946-47). It sailed on its first hunting expedition on December 22, 1946, and killed its first whale on January 29, 1947. In the next nine years its catch increased to 19,937 whales.

In 1948, the whalers were joined by two Japanese factory-ships and one Dutch, and in 1950-51 by the Panamanians.

Altogether there were 10,000 whalers in the Antarctic by 1951, of whom 7,000 were Norwegians, many of them working on foreign vessels. The number of whaling ships fluctuates constantly, depending on the demand for whale products. In the past five years there have been between 17 and 20 factory-ships and three coastal stations (Norwegian, British and Argentine) operating in the Southern Ocean. Apart from the *Slava* there were, in 1951, ten Norwegian factory-ships, three British, two Japanese, one South-African, one Dutch and one Panamanian (*The Antarctic Pilot*, p. 166).

In the 1953-54 season there were 17 factory-ships, and 19 in the following. Though that was approximately half of the prewar number, in tonnage it was about the same. The amount of oil produced in 1953-54 was 388,595 tons, which is equivalent to the quantity of fat yielded by 80 million sheep. Whale oil is more expensive than sheep's fat and is at present used for making margarine and

synthetic lard. Oil of inferior quality goes to make lubricants and is also used in tanning and chemical industries. Spermaceti is a valuable raw material for soap, cream and ointments.

Whale liver is used extensively in medicine, especially for the important Vitamin "A." The teeth of the Sperm Whale is a good substitute for ivory.

Even this far from complete list of uses to which whale oil may be put shows how extremely important whaling is.

Since 1945 whaling in the Antarctic is governed by an International Convention limiting the hunting season to four months in a year and prohibiting the killing of more than 16,000 conventional Blue Whales by all countries.

One Blue Whale equals two Fin, two Sperm, 2.5 Humpback or six Sei Whales, or approximately 20 tons of oil. Thus, 16,000 Blue Whales should yield about 320,000 tons of oil, but actually they yield more: the total for the 1951-52 season was 412,000 tons.

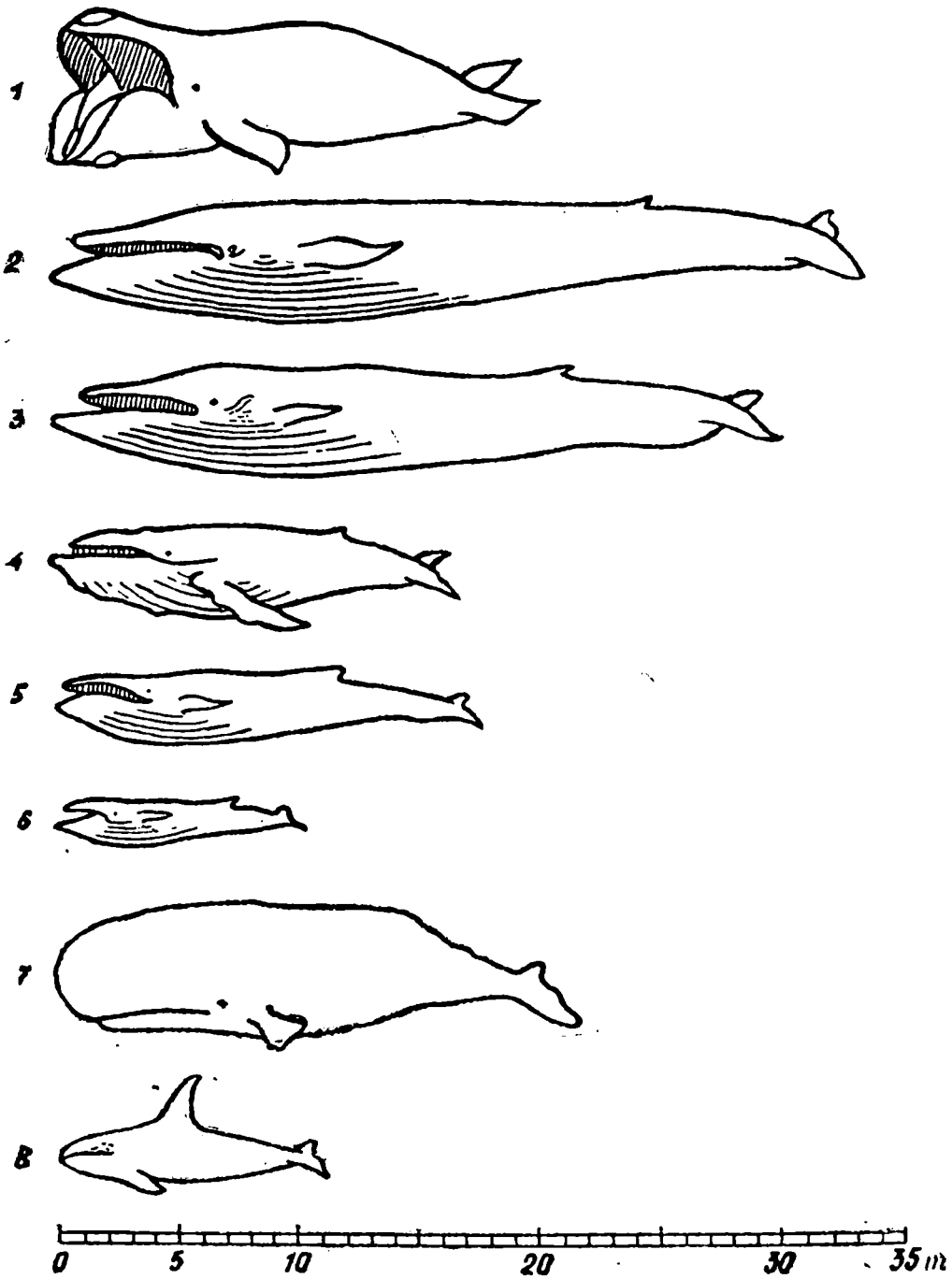
Annual profit from whaling in the Antarctic exceeds £3,000,000.

In most cases, the whales in the Antarctic are the same as in the Northern Hemisphere, though bigger in size. The only exception is the *Southern Right Whale*, which is to be found only in the Southern Hemisphere.

In size it is smaller than the Arctic Right Whale, or, as it is also called, the Greenland or Polar Whale.

The Southern Right Whale yields up to 20 tons of oil, 0.6 ton of baleen and edible meat. It is a slow-moving animal about 20 metres in length, with the head and huge mouth taking up a quarter of that. In the upper jaw there are about 700 plates of black, very springy baleen up to six and more feet in length. It is dark, almost black dorsally and ventrally, with white spots. The Southern Right Whale may be recognized by the high doubled spout and barrel-like body.

The stocks of the Southern Right Whales in the Antarctic proper had been seriously depleted even before man



How Antarctic whales compare (after B. A. Zenkovich and W. H. Dawbin) 1—Southern Right Whale; 2—Blue Whale; 3—Fin Whale; 4—Humpback Whale; 5—Sei Whale; 6—Minke Whale; 7—Sperm Whale (male); 8—Killer Whale

started hunting them there, probably due to seasonal migrations to warmer waters in the Southern Hemisphere. Only 588 were caught between 1904 and 1927, and since they are easy prey for the hunters it may be assumed that this was also the number encountered. To prevent their total disappearance, Norway in 1929 and other countries in 1931 agreed not to hunt Southern Right Whales.

As stated above, in the early years of regular whaling the object of the hunters was the Humpback, or the long-flippered whale, which yields up to 14 tons of oil and extremely tasty meat.

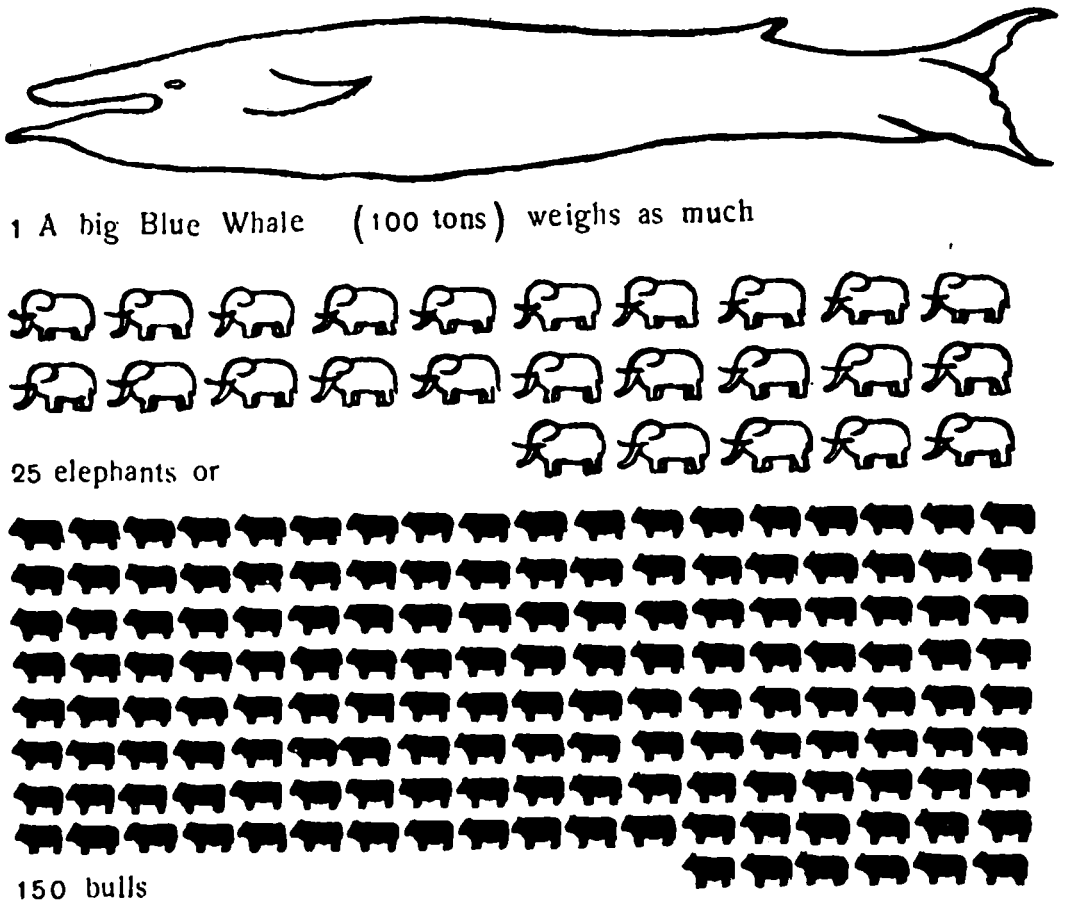
Encountered in big groups in the Antarctic, the Humpbacks seldom exceed 16-17 metres in length, have very big heads and about twenty wide grooves on their light-coloured under sides. The upper sides and the small dorsal fin are black. On the head and chin there are cutaneous-adipose swellings and knobs, and for that reason the Norwegians call the Humpback "knobby" or "lumpy" whale. The huge breast fins are up to four metres in length.

Females are much bigger than males, who seldom exceed 13-14 metres in length. New-born calves are about 5 metres long. Humpbacks feed on krills and deep-water shoal fish.

They are usually covered with coronule shells and to rid themselves of them the Humpbacks often approach islands or icebergs, since these parasites quickly perish in fresh water (according to B. A. Zenkovich's experiment, within 0.5-1 minute). It is usually near the shores that the Humpbacks are successfully hunted. Humpback-hunting is now limited to a few days in a season.

Whalers now hunt mostly for Blue Whales and Finbacks.

Blue Whales are the biggest of animals known, living or extinct. Some of them are 33 metres in length, weigh up to 160 tons and yield from 20 to 50 tons of oil and edible meat. Their 700 plates of baleen are up to 90 centimetres long each. The body is of slaty blue colour. Blue Whales swim extremely fast, up to 20 miles an hour. The numerous



A whale's weight (after J. Machowski, 1953)

grooves on the under side (some have as many as 120) facilitate movement in the water. Blue Whales are easily recognized by their original colour and high spout (up to 15 metres). They feed only on krills and unlike other whales never hunt for fish.

The Blue Whale's span of life, it is believed, is 20 years. Despite intense hunting, the Antarctic stocks of Blue Whales are still numerous.

The *Finback,* or Fin Whale, comes after the Blue Whale in size. It is usually 20 metres long, though there are some exceeding 27 metres in length. The Finback yields an average of 10 tons of oil. The meat is edible. The upper side is black and the under side white, with about 60-70 throat grooves. The dorsal fin is about 0.5 metre high. It

has 660 baleen plates, some of them 75 centimetres high, and feeds on plankton crustacea and shoal fish. Its life span is about 15 years. For a long time after the nursing period the calf follows its mother everywhere. Finbacks are the most numerous of big-size whales in the Antarctic and there are concentrations of hundreds.

The *Sei Whale* is considerably smaller. Its well-proportioned body seldom exceeds 20 metres in length. It yields between 3 and 4 tons of usable oil, its high-quality meat makes excellent tinned produce and its springy baleen is almost as good as that of the Southern Right Whale.

The Sei Whale's upper side is dark grey and its under side is white or bluish-pink, with 45-50 throat grooves. The dorsal fin protrudes sharply to a height of over 50 centimetres. It is the fastest of all the baleen whales and hunting it is a difficult thing. It feeds on krills, occasionally on small fish and on medium-sized cephalopods.

The Antarctic whales described above belong to the baleen category, with the Southern Whale representing the Right Whale group and the others the Rorqual group.

Of the Toothed Whales the only industrially valuable is the Sperm Whale. The Killer and Bottlenose Whales are not and for that reason are not hunted.

The *Cachalot*, or *Sperm Whale*, yields between eight and twenty tons of oil, including three to four and sometimes as much as eleven tons of spermaceti, depending on its size (there are Sperm Whales from 10 to 20 metres long). The oil is used chiefly in manufacturing lubricants and spermaceti in the perfume and chemical industries. Its meat is not edible. The Sperm Whale is the biggest of all toothed whales. The male is much bigger than the female. One-third of its body is the huge, but well-proportioned head. It has a big but rather flat hump on its black upper side and several protuberances on its tail. The Cachalot has only one, left, blowhole and a characteristically crooked spout. It has up to 57 teeth on the narrow lower jaw.

The Cachalot is polygamous and has a harem of between 20 and 40 females, grazing in the warm waters of the temperate and tropical latitudes. The owner of the harem zealously guards it from its rivals. The male progeny migrate to the Antarctic.

No sea animal will ever risk attacking a Cachalot. Even such a giant beast of prey as the squid with its 15-metre-long tentacles often falls victim to it (*The Antarctic Today*, p. 170). The squid, octopus and other cuttlefishes are the favourite feed of the Cachalot and it will descend to a depth exceeding 1,000 metres in search for them.

In the Cachalot's stomach one may find grey ambergris, a waxy substance formed as a result of indigestion. Some of these pieces weigh over 100 kilogrammes. Sometimes ambergris is found on the surface of the water or on the seashore.

Of late there have been reports of Norwegian and British whalers finding pieces of ambergris weighing almost 400 kilogrammes inside Cachalots. The price of ambergris, which was once worth its weight in gold, dropped sharply after the invention of the artificial substitutes now used in perfumery.

BIOLOGY AND WHALE INVESTIGATIONS

Many million years ago the whale was a land animal. It gradually grew to its present-day size after taking to water. To carry such a multi-ton body, a land animal would have to have an extremely powerful skeleton. For such giants water offers splendid conditions.

In water, the body of the whale assumed stream-lined forms. The forefeet became flippers, the hind-feet disappeared altogether and the tail assumed the form of a fluke. On the back there formed a cutaneous groove—the dorsal fin (in the case of fast-moving whales it sometimes exceeds two metres in height). The only thing remaining of the hair covering are patches of bristle on the head and

chin. The layer of fat covering the entire body reduces the whale's specific weight and preserves warmth, permitting it to go out into the cold waters. The temperature of the body is 38°C. Its skull has changed considerably and has become flat and long. The brain is very small and does not weigh more than 6-10 kilogrammes. By way of comparison, we may say that its tongue weighs from one to two tons. Its eyes have a permanent focal length and it does not see things clearly if they are near or far away. Whales are colour-blind, have no sense of smell, but do have a very good ear.

Despite the changes in its appearance and internal structure, the whale has remained a mammal. It has preserved the ability to breathe with its lungs, and penetration of water, even in small quantity, into its wind-pipe may prove fatal. The nostrils (blowhole) are far back on the head, near the highest point, and are first to emerge when the whale comes to the surface to breathe. It begins to blow while still under water and the air thus forced out produces a spout of water, and of vapour in the cold seas. Whales are recognized by the form of the spout. The flat head of an emerging Rorqual looks like a dark giant frog.

There was a time when whales were beasts of prey and some had as many as 200 teeth. They fed on fishes and other fast-moving sea animals. Today, most of the whales feed on krills and only some of them have teeth, and these they use as snapping organs. In most cases the teeth have disappeared, giving way to horny plates, the so-called baleen—a gigantic sifting apparatus perfectly capable of holding krills and little fish. The number of such plates, suspended from the upper jaw, is sometimes 800. Baleen Whales take in a mouthful of water with many krills, lock their jaws and push out the water with their huge tongues. The water seeps out through the plates, but the krills are held back, as if by a sieve, by the close-set baleen plates.

The instinct of self-preservation is very weakly developed. And that is quite understandable, for, apart from

Killer Whales, their only enemies are the whaling ships and they made their appearance comparatively recently. *Killer Whales* are small beasts of prey from 7 to 10 metres long and when in a pack they attack single and sick or weak whales. These attacks, however, are not frequent and may be likened to attacks by a pack of hungry wolves on a horse.

The first Rorqual was hunted down less than 100 years ago, at the time explosive harpoons and the slipway came into existence. Whaling in the Antarctic is a rather recent development, dating back only 50 years.

Rorquals move so fast they often escape their pursuers. They are quite capable of developing a speed of 20 knots, whereas whaling ships do not exceed 12-15 knots. Whales swim especially fast with the tide and in such cases there is no use pursuing them. But the feeling that they should get away from the noisy ship is almost completely undeveloped and they seldom take advantage of their speed. Pursued, the whales move with the tide and, after outpacing the vessel by several hundred yards, again begin to "graze." The boom of the harpoon gun or the explosion of the grenade frightens them, but they calm down very fast.

The hunt is a round of attempts to approach a group of whales. Sometimes the vessel succeeds in doing that by moving slowly, with the engine making very little noise; sometimes this is done at full speed, with a leap, as it were, before the whales have made a running start. As a rule, the whales dodge away from the pursuers, dive and re-emerge in the most unexpected spots.

A ship drifting with her engines dead does not scare whales. During our hydrological work at night we heard whales snorting and saw them spout as they rose to the surface close to the ship.

Rapid development of whaling and the huge annual catches have markedly depleted whale stocks and for that reason whale investigations and statistics are problems of utter importance. Latterly there have been many works on

these subjects, treating of such important questions as stocks, reproduction and migration.

To assess the stocks, it is necessary first to know how long whales live, how many generations exist at the same time, how fast whales mature, how often calves are born and how many of them a female bears in her lifetime.

It is very rare that more than one embryo is found in a dead cow and that proves that whales usually bear one calf after a period of gestation lasting between 11 and 12 months in the case of Blue Whales and up to 16 months in the case of Cachalots. The nursing period lasts between five and seven months and whales mature at the age of two or three. Thus, the comparatively low birth-rate is partly compensated by rapid maturation. It is assumed that a female does not give birth oftener than once in two years inasmuch as mating takes place in a definite season (late winter) and the female does not mate if she has a suckling calf, and the calf suckles a long time. Some authorities hold, however, that Humpbacks produce two calves in three years. Investigations of Fin Whales in the Atlantic sector of the Antarctic show that the interval between each calf is less than two years. Opinion is widespread, however, that Blue Whales and Finbacks give birth to one calf every three years (*The Antarctic Today*, p. 176). In brief, this very important problem has not yet been solved.

Investigations into the age of whales are also incomplete and are being carried out in two ways. The first applies only to cows and consists in counting the number of corpora lutea and that permits gauging the approximate longevity of the animal. The results of such studies have revealed that female Finbacks do not live more than 50 years and usually only 15 (*The Antarctic Today*, p. 177). These figures, however, are extremely approximative inasmuch as neither the period between births nor the number of years a female gives birth is as yet known.

Since 1940 scientists have been applying the method of determining whales' age by the structure of baleen plates, which bear traces of the annual cycle of growth. But with this method it is not possible to determine the age of whales beyond the age of six or seven because the plates become badly eroded and are replaced by new tissues.

Correct assessment of stocks requires knowledge of the course and periods of migration. That the whales cover extremely big distances is a thing every whaler knows, chiefly from the harpoons left in the body. The course of migration is now gauged chiefly by the skin parasites which come from all oceans. Whales gather for the summer in the Antarctic in big groups and in definite places. Towards winter they migrate northward, dispersing in the vast expanses of the tropical waters. But the course of migration was not known and no observations were carried out.

Whale-marking was introduced in 1926 and has since been carried out by scientists and whalers. A steel tube about a foot long is fired at the whale. It has a number, the name of the institution and the address where it should be returned if found. There is a special log with dates and places where whales have been marked. The marks are usually found in the blubber.

Marking the main types—Blue Whales and Finbacks—has not produced good results. Approximately 5,000 whales had been marked before the war and three per cent of them were killed. Most of the information thus obtained concerned Humpbacks and it was found that in winter they leave the Antarctic for the north along the South American, South African, Australian and New Zealand coast. For instance, one whale, marked off Enderby Land, was discovered near Madagascar (*The Antarctic Today*, p. 179). Humpbacks return to the Antarctic in spring, following the same course, and disperse in five groups in various parts of the Southern Ocean.

The chief factor determining the number of whales in the Antarctic is food. Almost all the baleen whales feed on krills (Euphausia superba), which, on their part, feed on microscopic zooplankton, chiefly on diatoms. The number of plankton depends on the physical and chemical properties of the water and the latter on circulation and concentration of chemical elements. The results of numerous hydrobiological studies and analyses of water samples show that the Southern Ocean is the richest in organic life (*The Antarctic Today*, p. 131). The quantity of nutrient salts which determine plankton development is much greater there than in any other ocean.

Different in temperature, salinity and other indices, the water mass of the Southern Ocean favours development of different types of plankton. Dawbin (1952), for instance, says that the distribution of krills is limited to regions where the temperature of the water does not exceed 3°C. Their concentration is also determined by local hydrological conditions. And inasmuch as whales usually gather in the regions with the greatest quantities of krills it may be said that in the final count whale distribution is determined by the same hydrological conditions. For that reason solution of the basic biological problems depends to a considerable measure on oceanography, which is their basis. And it is on this principle that oceanographical and hydrological surveys of the Soviet *Slava* whaling flotilla are based.

SEALS

All the known natural wealth of Antarctica—from coal reserves to rare metals—is insignificant from a practical point of view. The Antarctic's marine resources are another case—for years now seals and whales have been bringing man huge profits. Way back in the early 19th century tens of thousands of seal-skins were obtained every year on the

desert islands of the Southern Ocean and today tens of thousands of whales are caught every year.[1]

In the 1560's, Sir Francis Drake returned from the voyage, in the course of which he discovered Cape Horn, with the news that the islands in that region were "packed with seals which were so tame that they could be taken almost without effort" (E.W.H. Christie, *The Antarctic Problem*, p. 62). The precious skins of the Fur Seals were first brought from the South Atlantic early in the 17th century and from mid-century seal-hunting there became regular.

Fur Seals belong to the group of Eared Seals, which also includes the Antarctic Sea Lions. The group of True Seals, earless in outward appearance, consists of the Elephant, Weddell, Crabeater, Ross and Leopard Seals.

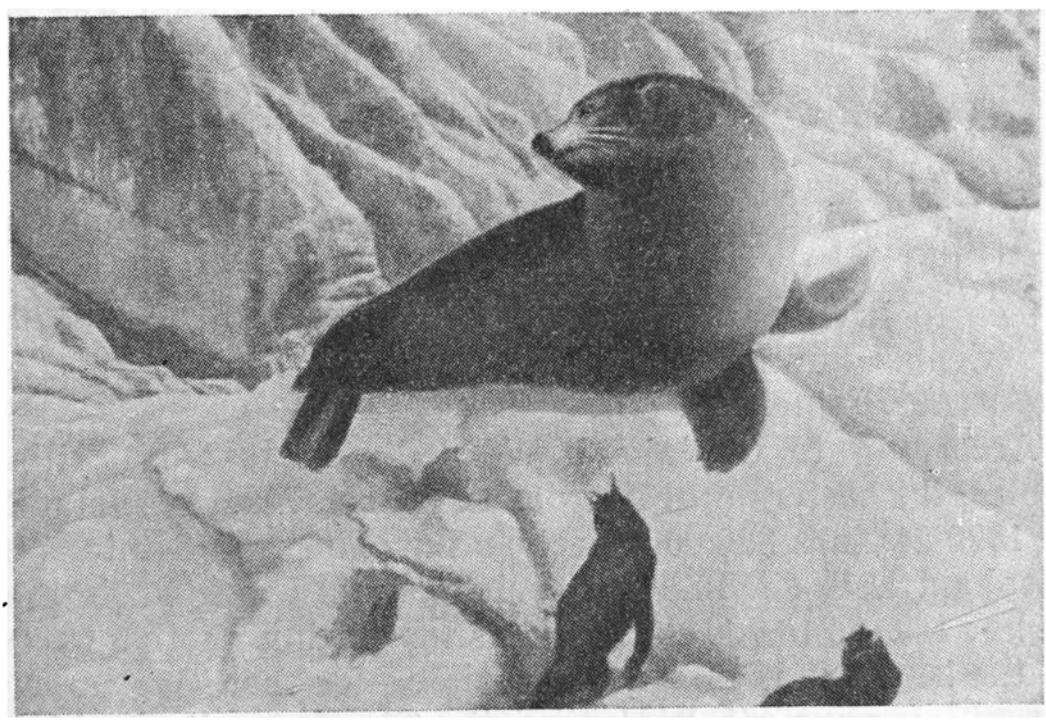
Fur Seals are the only species which have a rich undercoat of short, dense fur beneath the outer coat of longhairs. In size they are somewhat smaller than their kin, seldom exceeding 2.5-3 metres in length. The coat is dark brown, with light shades on the back. Fur Seals are also called "Sea Cats," but apart from the bristling moustaches they have nothing in common with cats. British sealers, for instance, call them "Sea Bears," and that is also the name they are known by in France and Germany. In summer, Fur Seals form huge breeding colonies, consisting of harems of ten and more cows. They give birth to one pup a year and the pups remain on the breeding ground and are suckled for several months. It is only after they have assumed the first coat of hair that they enter the water and start hunting for fish and cephalopods. Adult seals often feed on sea birds and penguins.

Southern Fur Seals inhabited the northern regions of the Antarctic and the coasts of South America (up to Chile and La Plata), South Africa and New Zealand. Up to mid

[1] According to *Antarctic Sailing Directions*, Moscow, 1948, the quantity of whale oil obtained in the Antarctic in the 1945-46 season was equivalent to 180 tons of gold, or $200 million.

18th century their skins were not highly valued because they were not so beautiful and soft as they are now—a thing due to the fact that no one knew then how to rid the skin of its long, hard hairs. New methods of processing the skins and of rooting out these hairs without spoiling the soft undercoat were invented in 1750 in China, which got its skins from the Aleutians, and in 1796 in London. The skins assumed their present-day appearance and became very fashionable in China. The demand was so high that the Aleutians could no longer meet it. The Chinese invention revolutionized sealing and resulted in a "gold rush" that lasted almost 70 years.

News that the Southern Fur Seals were similar to those in the north brought the entire American and British sealing fleets to the Cape Horn region. Sealing there began in 1766 at the Falkland Islands and in 1775 spread to South Georgia (the foremost of the Antarctic islands), although the northern rookeries had by that time not yet



Fur Seal (from *The Antarctic Today*, 1952)

been exterminated. An American sealer, Captain Fanning, reported that more than one million skins were secured at Masafuera Island, off the Chilean coast, in 1798 and delivered to Canton (E.W.H. Christie, *The Antarctic Problem,* p. 64).

Seal-hunting became a regular thing in the Antarctic early in the 19th century. In 1799, British sealers hunted at Kerguelen Island. Sealing became systematic at South Georgia in 1800 and in the following year 122,000 seals were exterminated.

The first sealers to visit the Antarctic were surprised by the vast number of seals there and wrote that the shores were literally "fur-lined." The British sealer Fildes said "it was impossible to haul up a boat without first killing a way ashore" (E.W.H. Christie, *The Antarctic Problem*, p. 66). In 1810, Captain Hasselbourgh discovered Campbell and Macquarie islands where he exterminated 15,000 seals. The haul for two seasons brought away from the Antipodes Islands by the first sealing gang was 60,000. At that time the price of a skin on the Chinese market was £1, but the sealers actually made more money by exchanging them for Chinese goods. R. Owen, for instance, writes of a case where 45,000 fur seal skins brought £52,000 (*The Antarctic Ocean*, p. 47).

When Captain Smith, who discovered the South Shetlands in 1819, visited the islands a year later he saw "from fifteen to twenty British ships with about thirty sail of Americans" hunting seals there (E.W. Hunter Christie, *The Antarctic Problem,* p. 85).

According to Captain J. Weddell, the famous British sealer, the sealers operating at the South Shetland Islands in 1820-21, took 320,000 precious fur skins and 340 tons of Elephant Seal oil. In 1821, sealer Daniel Clark wrote that he had taken "18,000 skins and as for getting another cargo in the island it is utterly impossible—for there is scarcely a seal left alive" (E.W.H. Christie, *The Antarctic Problem*, p. 95).

No sealer visited the South Shetlands for about 50 years and Fur Seals reappeared there, though in smaller numbers. It took sixteen years, from 1872 to 1888, for the sealers to exterminate the new rookeries. The extermination of the rich stocks on South Georgia was just as fast. In 1820-21, there were 21 vessels with 3,000 men seal-hunting in this region. Weddell visited the island in 1822, but found very few seals there. In the two years before that the number of seals exterminated reached 1,200,000 (*The Encyclopaedia Britannica,* Vol. XX, p. 243).[1]

Thus, big colonies were massacred wholesale and often rookeries were exhausted never to recover. Hunting became unprofitable and attempts were made to compensate for the losses by filling the empty holds with the oil of indiscriminately killed seals and even penguins.

In their search for new rookeries the sealers often went on long expeditions, discovering and rediscovering Antarctic islands: Campbell, Macquarie, South Orkneys, Balleny, Palmer archipelago, and even parts of the continent, such as Enderby Land, which was first visited by the sealers of the Enderby House;[2] Sabrina Coast, named after one of the ships lost in the Antarctic; and Graham Land. The most outstanding discoveries were made by the sealers Palmer, Weddell, Biscoe and Balleny. Many of them remained unknown, for the sealers were a secretive lot and left few, if any, accounts of their tough and bloody business—newly discovered rookeries were to them like mines of precious metals of which they did not care to tell their rivals.

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[1] Other sources say this figure of Weddell's is for a period of 25 years (E.W.H. Christie, *The Antarctic Problem,* p. 65) and even 48 years—from 1778 (*The Antarctic Pilot,* p. 71).

[2] The Enderby Brothers, a London firm, first began to send its ships to the southern seas in 1785. The object of some of the voyages was geographical survey, and financially they were unprofitable. One of the owners of the firm, Charles Enderby, was a founder member of the Royal Geographical Society, established in 1830.

The *Elephant Seal* is the biggest of the Antarctic seals, and the most valuable after the Fur Seal. The massive animal is between three and six metres long and weighs between 2.5 and 5 tons. The bull has a big trunk which inflates to a length of almost one metre if the animal is angered. The body is covered with stiff light brown or brown hair; new-born pups have a silky black coat. Mature animals feed mainly on cephalopods, which they swallow because, as in the case of all other seals, their cheek teeth are degenerate. The layer of fat of one big animal yields half a ton and more oil. Its meat is edible, the flippers being particularly valuable.

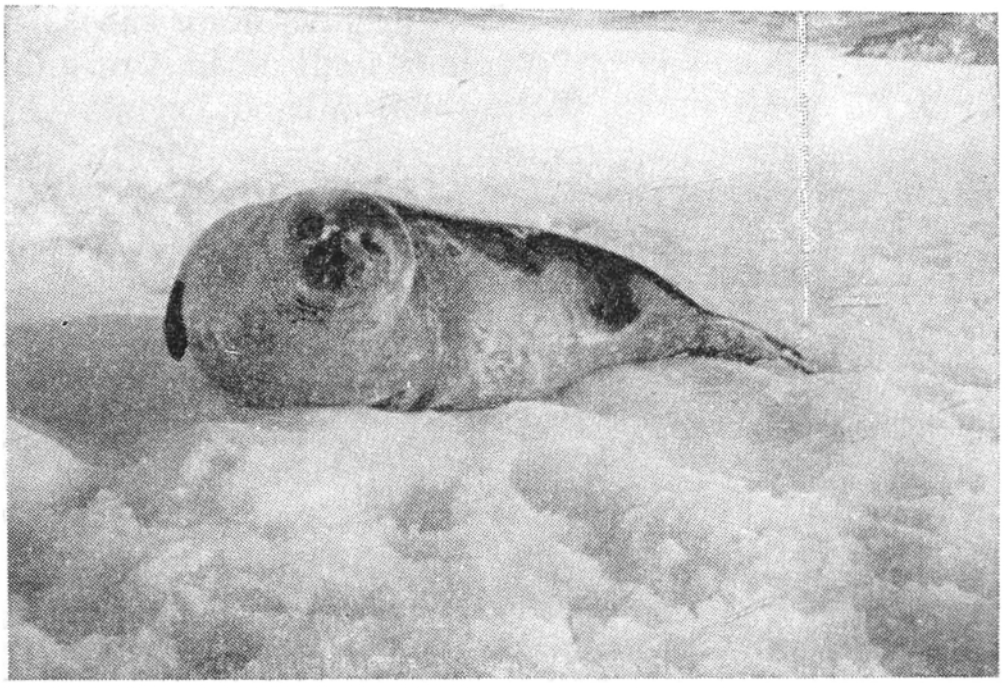
Sealing vessels plying the cold waters of the Southern Ocean found the Elephant Seal a quarry worth pursuing, for it brought high profits. According to Owen, the 250 tons of Elephant Seal oil brought back from the South Shetlands in 1820-21 were sold at £12 a ton. Elephant Seals were taken in smaller numbers than Fur Seals, but for a much longer period, and eventually shared their fate. They had become practically extinct on the Falkland Islands by 1870, on Macquarie Island by 1878 and on South Georgia by 1885 *(The Antarctic Today,* p. 202).[1] In 1907-13, this species was almost wholly destroyed on the Crozets and Kerguelen Island.

Sea Lions, which had their breeding places in the immediate vicinity of Fur Seal rookeries, were badly decimated too. Their skins went to make leather, but they yielded less oil than Elephant Seals and for that reason there are still numerous colonies of them on the islands of the North Antarctic. They are called Sea Lions because the bulls have massive manes on their necks and shoulders. Much like Fur Seals in appearance, they are somewhat bigger, being three to four metres long. The bulls have dark brown coats which make them conspicuous amidst

[1] Sealing in South Georgia has been regulated since the 1880's and, as a result, the number of Elephant Seals has increased to more or less the original number.

the yellowish cows and pups. Sea Lions feed on krills, cephalopods and fish. At present they are hunted in small numbers.

Weddell Seals, so called because they were first described by Captain Weddell, are the most numerous and the most scattered in the Antarctic region. Slaty grey, with

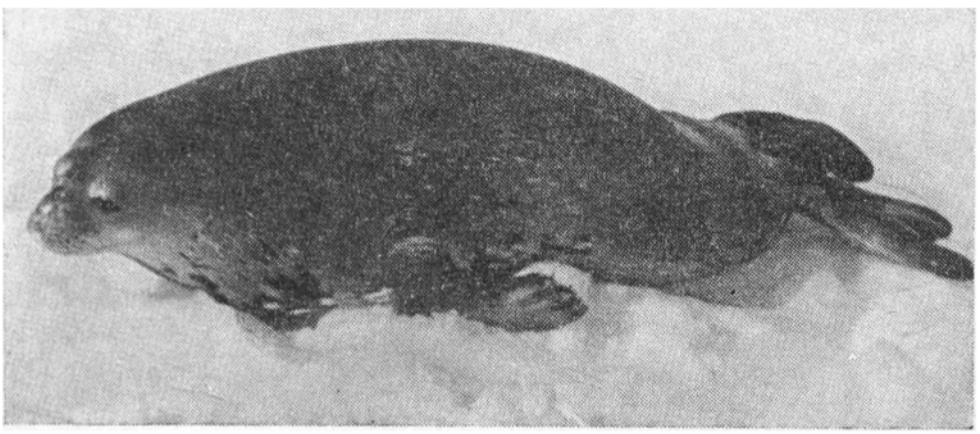


Weddell Seal in the Bunger Oasis (Soviet Antarctic expedition)

a mottling of white and silver on the underparts and an almost black back, the Weddell Seal is a sluggish animal between 2.5 and 3 metres in length. It spends the winter in the far south, near the rigorous shores of Antarctica. It remains under water most of the time and comes up only for air, depending upon breathing holes which it takes care to prevent from freezing. In summer, big colonies of 200-250 Weddells scatter over solid ice-floes or occupy the shores on the numerous uninhabited islands.

In spring and summer, the pack-ice in the Antarctic is dotted with *Crabeater Seals,* which usually herd together in groups of hundreds. They live in the open sea, between

the edge of the land-fast ice and the northern boundary o the pack-ice. They spend the greater part of their lives o floes and rarely come ashore. As a rule, they are seldor more than 2.5 metres long. In winter Crabeater Seals hav lighter coats than in summer, varying from brownish t yellowish. In the case of adult and particularly old Crab eater Seals, the moult results in a change of colour t



Leopard Seal (Soviet Antarctic expedition)

white, sometimes with a reddish shade, and that is wh they are also known as White Antarctic Seals. The foo consists mainly of krills. The teeth are adapted as a siev and, like whales, Crabeater Seals strain the water out o the mouth, taking in only the krills. Crabeater Seal mea does not smell of fish and is quite edible.

The *Leopard Seal* is different from the other species. I is powerful, agile and fast both in water and on ice. Th cows are somewhat bigger than the bulls, averaging 2.5-3.5 metres in length (though some are even 4 metre long) and weighing half a ton. Hermits by nature, Leopar Seals never herd together in big groups, even during th breeding season. They wander extensively and may b

encountered all the way from the coast of Antarctica to Australia and Patagonia, spending most of their lives in water and on ice and rarely coming ashore. The long body and the snake-like head are dark grey in colour, splashed and spotted with bright yellow and black. No other species possesses the carnivorous habits of the Leopard Seal. Though the usual food consists of fish and cephalopods, it also feeds upon penguins. The stomach of one of them was found to contain the remains of seventeen Adélie penguins *(The Encyclopaedia Britannica)*. Sometimes the Leopard Seal attacks other seals, especially Crabeaters, and is not averse to feeding on the carcasses of whales. Its main weapon is its teeth, but they cannot save it from its only enemy, the Killer Whale, which goes after seals in water. The meat of the Leopard Seal is inedible.

The *Ross Seal* is the rarest and least known of all the species and inhabits the southernmost, least accessible regions of the Antarctic, herding in small groups. It is distinguished by its clumsy body with a small head and almost no neck, and by its ability to bellow almost melodiously. It is greyish-brown or black above and paler below, with oblique streaks on the sides. The thick layer of fat gives it the appearance of sluggishness. The Ross Seal is an excellent swimmer thanks to its well-developed flippers and lives mostly in the open sea. Like the Leopard Seal, it is a hermit, feeding mostly on cephalopods and sometimes on seaweeds. The main reason why so little is known of the habits of the Ross Seals is that they are very few in number and are not hunted. In fact, only 50 had been seen up to 1951.

The oil, skin and fur taken from pups of all the species brought less profit than the skins of fur seals. After a brief period of intense sealing and decimation of rich rookeries the take dropped sharply and sealing vessels visited the Southern Ocean more and more rarely, though in the remote parts of the region sealers continued to hunt successfully. In the early 1890's, a Scottish whaling expedition

to the Ross Sea returned with the last big harvest of 20,000 skins (*The Encyclopaedia Britannica,* Vol. XX, p. 243). Only two Norwegian vessels—the *Hertha* and the *Gastor*—went sealing in the Antarctic in 1893-94. In the year after that there was only one schooner hunting Elephant Seals in the area of Kerguelen Island.

The study of the Antarctic by the sealers is actually limited to the years when seal-hunting was at its peak (1800-30).

The reason why the seals were exterminated so fast was not only because they herded together, but also because they had almost no instinct of self-preservation on land, their only enemy being the Killer Whale.

E.W.H. Christie describes how sealers, armed with clubs and spears, attacked sleeping seals, with the latter making no attempt whatever to save themselves. "Centuries of immunity on land seem to have atrophied the suspicious instincts of all Antarctic animals," he writes. "An old bull in the midst of his harem might rear up and roar at the intruders, but the mild-eyed cow seals would watch with incurious eyes the skinning of their nearest neighbours or fall asleep among the reeking remains until their turn came to be clubbed or flayed before the cold had stiffened their limp bodies" (*The Antarctic Problem*, p. 66).

During our *Slava* voyage in the Antarctic we killed seals for scientific purposes and were always surprised by their passivity and utter lack of fear of man and ship. One day we saw two light brown Crabeater Seals in the pack-ice near the coast. The furry animals lay on a floe, their heads together and watched the whalers unperturbed. They did not raise their heads even when the vessel hit the floe. One of the seals was shot through the head, but the other did not even move to see what was happening. It was only after it had been wounded several times that it turned tail and fled across the snow. When one of the sailors was catching up with it, the wounded animal swept around, roared at his pursuer and then again continued its flight.

Hunting southern seals has been restricted now, the operations being limited chiefly to the few colonies established on some islands in the Antarctic and beyond. Sealing in the Falkland sector has been regulated since 1881, and extermination of fur seals there has been prohibited *(The Encyclopaedia Britannica)*. Figures for 1926 reveal that 13,000 seals were taken on the main islands of the Falkland sector. On South Georgia, hunting is allowed only from March to October and only 6,000 Elephant Seals and Weddell bulls are permitted to be killed each season. In actual fact, according to the British press, the take in 1951 was only half of that number. Macquarie Island has been turned into a seal and bird preserve. There are small colonies of Fur Seals on South Georgia, Bouvet and Crozet islands, as well as near New Zealand and on the shores of Australia, Tasmania, South America and South Africa (South Polar Chart, Hydrographic Department, London, 1949).

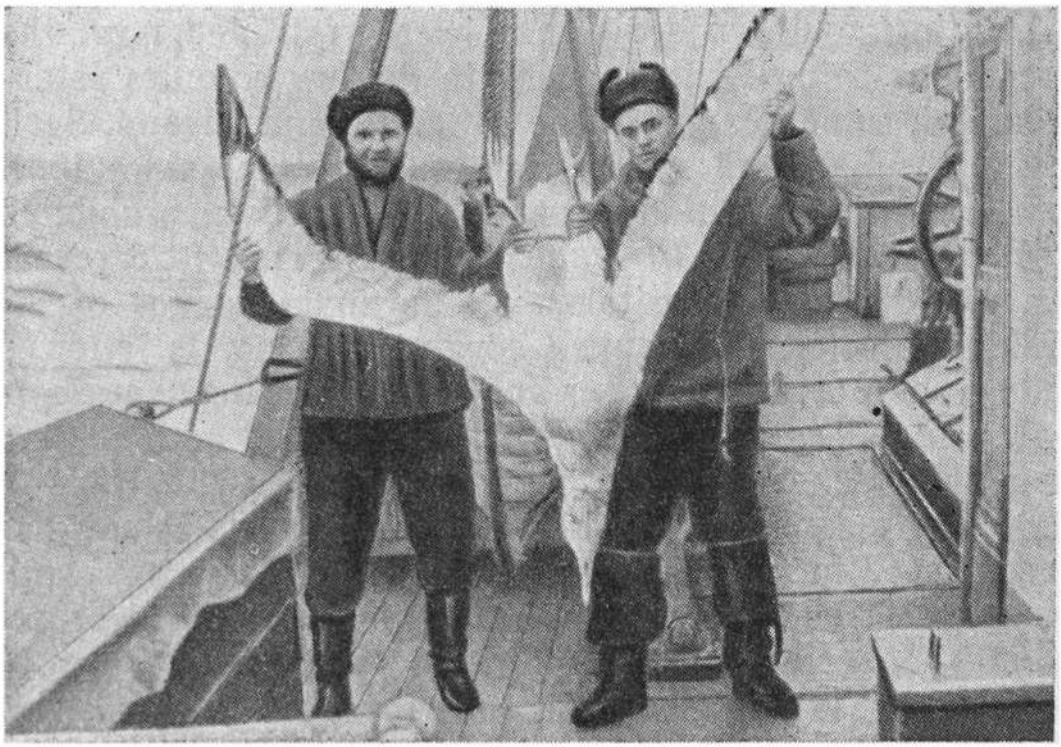
We encountered small groups of these animals in 1954 at the entrance to Capetown's Table Bay.

BIRDS

There are only about twenty species of truly Antarctic birds, but the total number is vast and in summer it increases at the expense of those arriving from the more temperate regions. Almost all of them are sea birds and their life is inseverably linked with the water, which abounds in rich and diverse foods, especially in the warm seasons. Many of the petrels, for instance, find it difficult to move on land and can fly off only from the water.

South Georgia is the only Antarctic island where there are land birds—but only three species.

The *Pipit—Anthus Antarcticus*—is a singing bird which, Christie says, is very much like the English lark. It spends all its life on South Georgia and its warbling simply does not fit with the island's austere nature. Another species is



Wandering Albatross aboard the *Slava-15* (photo by V. Vikorezov, 1955)

the *South Georgia Teal—Nettion Georgicum.* And the third is the *Sheathbill—Chionis Alba*, which is a distant relative of the plover and the gull. Though a shore bird, it is an expert swimmer and flyer, often visiting the South Orkneys and Graham Land, and it is off the coast of the latter that we saw it on several occasions. In the air the sheathbill looks very much like a white dove and is often mistaken for one.

The king of birds in the Southern Hemisphere is the *Wandering Albatross,* which can cover about 500 kilometres a day. Its wings may span between 3 and 3.5 metres, its plumage is white except for the extremities of the wings and the tail which are black.

The Wandering Albatross may be encountered anywhere between the edge of the ice and the "roaring forties," where the constant storms and winds enable it to stay a long time over the ocean. Among the nesting islands are South Geor-

gia and the Crozets. Both the male and female take part in building the nest, hatching and feeding the nestling. It takes a long time for the chicks to become feathered and to learn to fly. Their plumage passes through several stages of mottling, but it is only in the fourth year of their life that it finally becomes almost snowy-white. Like most Antarctic birds, the Wandering Albatross feeds on invertebrates, fish and offal of killed whales.

The *Light-Mantled Sooty Albatross* is somewhat smaller in size, with a wing span of about two metres and ashy-grey and grey-brownish plumage. It nests in small groups on South Georgia, Kerguelen, Macquarie and other islands. The Sooty Albatross may be encountered all over the Southern Ocean south of 30°.

One of the most numerous birds in the Antarctic is the *Cape Pigeon,* which belongs to the petrel family. It is between 30 and 40 centimetres long, with a wing span of 80. Its plumage is black and white, with its under side snowy-white, and for that reason it is also called lemming. Cape Pigeons flock around ships in such large numbers that it is not difficult to catch them with bare hands.

Cape Pigeons are also encountered north of the equator. They nest in big groups on cliffs and feed on small invertebrates, fish and offal of killed whales.

Antarctic Petrels resemble Cape Pigeons and are just as numerous. The upper side is brown and the under side and extremities of the wings are white. Like most petrels, they have become so accustomed to living on water that they find it hard to walk on anything solid and cannot fly off from a deck.

Antarctic Petrels build their nests on the Antarctic coast and usually inhabit pack-ice areas. In recent decades they have been encountered increasingly often north of these regions, accompanying whaling ships which in summer are an excellent source of food for all sorts of birds.

The *Snow Petrel* is a useful indicator of the distance between the observer and a pack-ice. Though similar in

size to the pigeon, it flies deep into the interior of the continent and is not afraid of any weather. Snow Petrels build their nests in the crevasses of cliffs and live in small colonies on the Antarctic coast and off-lying islands. They feed on crustaceans and sometimes small fish.

The *Giant Petrel*, the most ubiquitous of scavengers, has plumage of grey-brown, a wing span of up to two metres and, in addition to hunting for cephalopods, fish and crustaceans, often attacks penguin nests, devouring the eggs and the young. It also likes seal and whale meat. Early in spring Giant Petrels flock to the Antarctic shores to build their nests and breed.

Of the various species of petrels in the ocean one sometimes encounters the *Silver-Grey Petrel.*

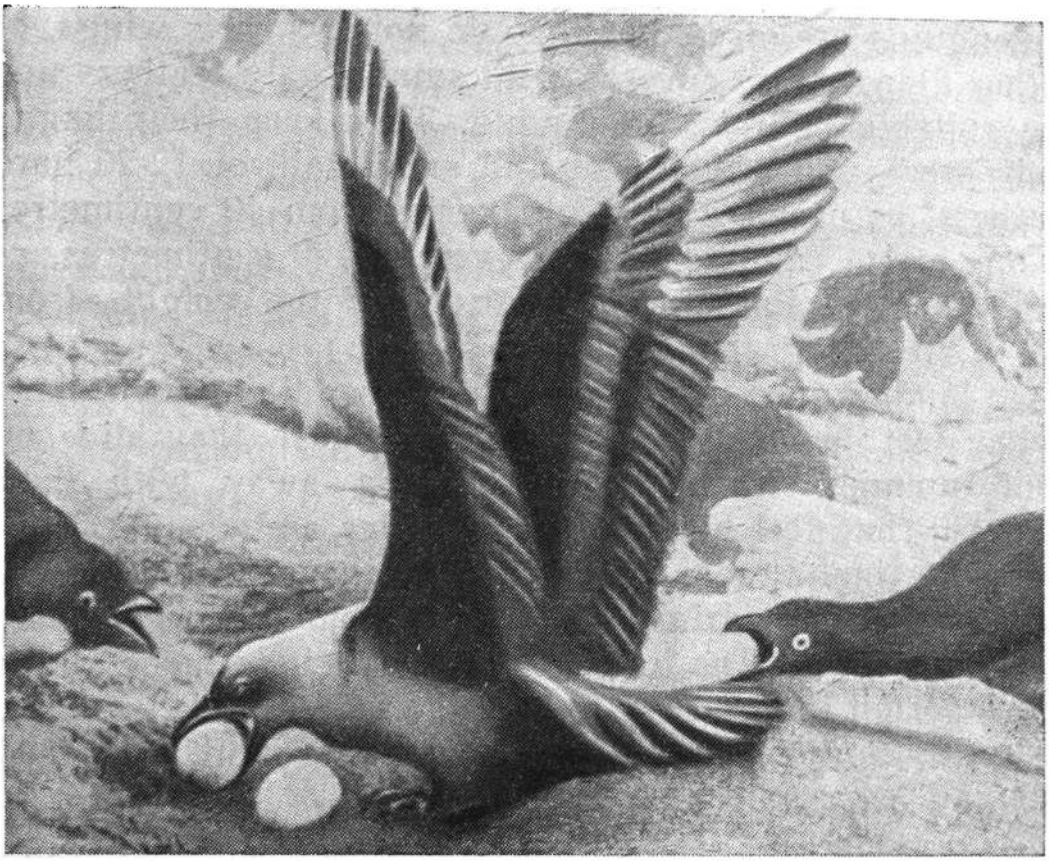
Smaller petrels include the *Wilson Petrel*, which reminds one of a beautiful, swift martlet.

Apart from petrels, the Antarctic and the regions to the north, abound in *Skuas*, which belong to the family of gulls.[1] They are extremely predatory and are the enemies of all other birds, destroying their nests and devouring the chicks of penguins and other birds, attacking small birds and stealing their food.

The South Polar Skua is grey-brown in colour and its wings may be spanned up to 1.5 metres. The brown Skua is somewhat bigger and darker than the others. In spring Skuas migrate from the northern Atlantic islands to the southern and settle down near the colonies of other birds. While destroying other birds' nests, they take good care of their own and look well after their young. The Skua is a splendid flyer and Scott saw one in 87°20′S., in the interior of Antarctica, more than 1,000 kilometres from the coast (*The Antarctic Pilot*, London, 1948, p. 338).

The most characteristic and original of Antarctic birds are the *Penguins*, ancient birds that had lived through the Ice Age on this once warm continent. There is every justi-

[1] Old records refer to them as "Egmont Harbour Chickens."



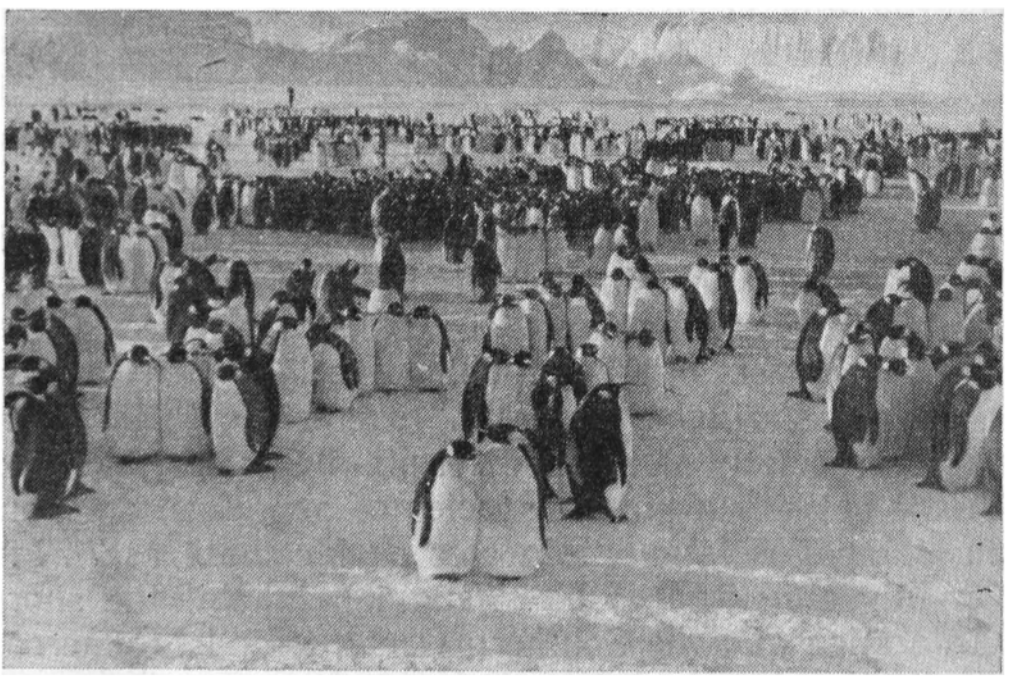
Skua attacks an Adélie Penguin nest (E. H. Forster, 1953)

fication to call them masters of land and ice in the Southern Hemisphere. There are no penguins north of the equator, although the very name (probably from the Latin "pinguis"—"fat") originally referred to the big auks which inhabited in great numbers the North Atlantic islands. With the discovery of the non-flying species in the Southern Hemisphere, the name "penguin" was given to them and it stuck, especially after the extermination of the big auks.

Of the seventeen known species of penguins, only one, from Galapagos Island, migrates as far south as 7°. Five never migrate north of 60°. Penguins inhabit the shores of Antarctica and the Southern Ocean islands. Some concentrate in places sheltered from storms, others (like Adélie Penguins for instance) prefer open beaches on which they build their nests of pebbles.

Penguins are birds, but they do not fly. Their wings, or rather flippers, are covered with small, scaly feathers and are suitable only for swimming. They keep their baggy body erect, using their feet and small tail, of 12-20 hard feathers, as props. The height varies from 40 centimetres to one metre (and sometimes even to 120 centimetres, as in the case of Emperor Penguins) and the weight—from five to fifty kilogrammes.

On land and ice penguins jump or waddle on their short webby feet. When they have to move fast, they slide on their tummies on the snow, pushing away with their flippers. They feel much better in water and spend a considerable time at sea. It is there that they find the food to eat and water to drink. In fact, without sea water they cannot live long. The tongue has sharp studs turned back which permit the penguin to hold the food it finds in water. Penguins cannot pick up food from the ground. They feed on small fish, squid and crustaceans.



Emperor penguins off the Davis Sea coast (Soviet Antarctic expedition)

The strong beak is covered with several separate horny plates and not with a single sheath as is the case with most birds. The head, back and wings are usually black, and the breast and stomach white. Each species, however, has its own pattern and shades and often yellow-gold stripes and spots.

Penguins are well adapted to the rigours of the Antarctic climate. The thick layer of fat and the dense coat of feathers protect them against the cold and wind. In the moulting period, old feathers are not shed until new ones start growing.

Penguins are monogamous. Most of them lay two eggs at a time, the bigger species—one. Emperor Penguins and King Penguins incubate their egg by holding it between their feet. Here is how Bellingshausen described the King Penguins during the breeding season: "We saw each bird holding an egg between its feet, pressing its nose to the lower part of the stomach, in which the egg makes a small depression. The other side of the egg lays on the feet, and is thus held very strongly. In order not to drop the egg, penguins jump on both feet instead of running (F. Bellingshausen, *Double Quest in the Antarctic Ocean and Voyage Round the World in 1819-21*, p. 273).

Hatched in spring or in summer (each species has its own hatching season), the chick takes a year or a year and a half to fledge. Penguins are extremely solicitous about their progeny. They heroically defend their nests and eggs against birds of prey. The whole colony, and not only the parents, gather food for chicks.

The Australian Antarctic expedition of 1954 reported an extremely interesting case. When the *Kista Dan* approached a 20-mile strip of land-fast ice off the shore, the sailors saw "a long line of thousands of Adélie Penguins stretched, like ants on a concrete path, across the ice to the mainland and off-lying islands." The clumsy birds had to travel far to the sea to get food because the ice had not yet begun to melt. On the shore the members of the expedi-

tion discovered a penguin colony and found that half of all the chicks had starved to death and those remaining "would chase any returning adult for hundreds of yards screaming for food" (Ph. Law, *The Australian Antarctic Expedition to MacRobertson Land*, p. 417). Some penguins feed their chicks for a year and even more.

Penguins migrate annually to the south for breeding purposes, but the dates, direction and distance of these migrations, and the breeding places, are by no means the same with all species.

Emperor Penguins may be found all over the Antarctic coast, and even as far as 80°S. In the north, they are encountered farthest on the South Shetland and South Orkney islands. The Emperor Penguin is the biggest of all penguins, being 115-120 centimetres high and weighing 50 kilogrammes. Its head and back are black, the white stomach and chin are divided by a black strip on the neck, and there are yellow spots near the ears.

For their breeding places they choose spots not too far from crevasses or polynias, in order not to make food-getting difficult. They do not build nests and cluster close together at the walls of cliffs. They begin laying eggs and hatching in the coldest season of the year, when the temperature is minus 50-60°C. Only one female in every five or ten lays eggs, each weighing about 450 grammes. Most of the birds hold round bits of ice and stones on their feet and take advantage of every possibility to steal their neighbours' eggs. Incubation lasts about two months and during this period penguins do not eat.

The fluffy silver-grey chicks are usually hatched in early spring, at the end of August. In November, Emperor Penguins begin their northward migration on floes. The moulting season sets in January, in mid-summer, and it is then for the first time that young penguins begin to look for food by themselves, but it takes them one and a half years before they fledge. After that they migrate to the

breeding grounds in the south. It is presumed that Emperor Penguins live more than thirty years.

The *King Penguins* live north of the Emperor Penguins. They are slightly smaller in size and brighter in colour. The head of a King Penguin is black with greenish shades, the green-yellowish neck is striped bright yellow on the sides, and the stomach is snowy-white. A great many of these harmless birds have been killed for their beautiful skins.

The habits of the King Penguins are somewhat different. They lay one big egg in summer, in December or January. The young, covered with long grey down, appear a month and a half later. The adults take loving care of the chicks and feed them for two seasons, even when they have been fully fledged.

The most numerous of the species are the crested *Royal Penguins*—in the North Antarctic there are colonies of hundreds of thousands.

The Antarctic coastline and the islands south of 60°S., the South Shetlands excluding, abound in *Adélie Penguins*, which seldom exceed 80 centimetres in height and weigh about 6 kilogrammes. The back, head and neck of an Adélie Penguin are bluish-black, the abdomen and breast—snow-white. They build their nests of pebbles and for that reason they settle down in open spots where snow is swept away by the wind. Adélie Penguins often fight one another for nesting grounds and building materials. The nest is built and guarded against thieving neighbours by the female, with the male gathering the pebbles.

Adélie Penguins usually lay two eggs and incubate them for about five weeks. The dark-grey chicks are fledged very fast and are extremely voracious. To feed them, the adults constantly hunt for crustaceans, small fish and squid. When they are away hunting, the chicks are looked after by a few old penguins, which bring them up and take them into the water after they have been fledged.

On the remote Antarctic islands and in the subantarctic region one comes across *Macaroni Penguins.* The sailors of Bellingshausen's *Vostok* and Lazarev's *Mirny*, who saw them on Zavodovski Island and South Georgia, called them "Mandarins" for their bright colours. The Macaronis have two bright, goldish crests that start as a thin strip from the yellow or red bill. There are white strips on the front and rear edges of the wings, and a big white spot on the inside. These birds are usually about 60 centimetres in height. They do not walk, but hop with both feet up in the air.

Macaroni Penguins lay one egg, usually some time between September and December. The chicks are fledged in less than six months. In winter, the Macaronis migrate north as far as La Plata, South Africa and New Zealand.

In summer, the continental coastline and the off-lying islands are full of *Ringed Penguins*, which are very much like the Emperor Penguins in colouring, but much smaller in size—from 40 to 50 centimetres high. They lay eggs from December to February and the first chicks are hatched in January. In winter, they migrate to South Georgia and the Falkland Islands.

On the South Shetlands, South Orkneys, South Georgia and other islands there are penguins which the British call *Gentoos.*[1] They are small (about 0.5 metre high) and are distinguished by a gold strip of short feathers across the forehead and around the eyes.

The numerous colonies, totalling between 500,000 and 700,000 early this century and up to 1,000,000 during the nesting period, were mercilessly exterminated for oil—although all the oil a bird yielded was worth "only one sou"—and beautiful plumage (C. Vallaux, *General Geography of the Seas,* Russ. Ed., p. 96). The sealers destroyed the penguin colonies wherever they met them in the Southern Ocean.

[1] Pygoscelis papua (Lat.)—*The Antarctic Pilot,* London, 1948, p. 64.

About 250,000 penguins were killed annually on Macquarie Island alone. In 1933, this island was proclaimed a preserve, while on all the other islands hunting them now requires special permits.

The funny and trustful birds are the Antarctic explorers' only friends and diversion, and their habits are described in a great many books. Penguins are not in the least afraid of people and dogs, and are very sociable. Owen (*The Antarctic Ocean*, p. 51) writes of close friendship between a penguin and a cat the sealers brought with them to Seal Island. The cat, it seems, reminded the penguin of a fluffy chick and every day it brought it crustaceans to eat.

Antarctic birds are edible and the meat of most of them is considered very tasty. The only exception is the Giant Petrel.

MARINE FLORA AND FAUNA

Animal life in the Southern Ocean—in this case, the bigger of its inhabitants, whales, seals, fish and birds—depends for its ultimate sustenance on the huge number of plankton it contains. Plankton (Greek for "wandering") consists chiefly of microscopic, vertically floating plant and animal organisms with extremely limited capacity of moving independently.

The dominant constituents of the phytoplankton in the Antarctic are the *diatoms*—single-celled plants usually not visible to the naked eye. Armed with a microscope, one will notice that they are brown, the colour being caused by a pigment—diatomin. The outstanding characteristic of the diatoms is an ornamented siliceous "shell." Present in immense numbers, they may stain the blue sea-water green and even brown. The most marked increase of the diatoms in the Antarctic occurs in October and November, and the lowest concentrations are recorded in July and

August. These seasonal fluctuations depend on the changes in the duration of sunlight, water temperature, salinity, ice-floes and other causes.

The diatoms constitute the main food of the krill (Euphausia superba), the leading species of the Antarctic zooplankton. Euphausia superba itself is the main food of the bigger marine animals, from fish to baleen whales. Between one and two and a half inches in length, it is almost transparent with numerous brick-red dots on its body and legs, and big protruding eyes.

Like other plankton, Euphausia superba reproduce in incalculable numbers in summer, changing the colour of the sea-water to yellowish-brown. Krill concentrations are called "food spots," "food fields" or "whale stew." (Whales grazing on these "fields" usually sharply reduce their numbers.) As we have mentioned above, plankton is the main food of whales and other animals and for that reason it is extremely necessary to know its distribution and migration.

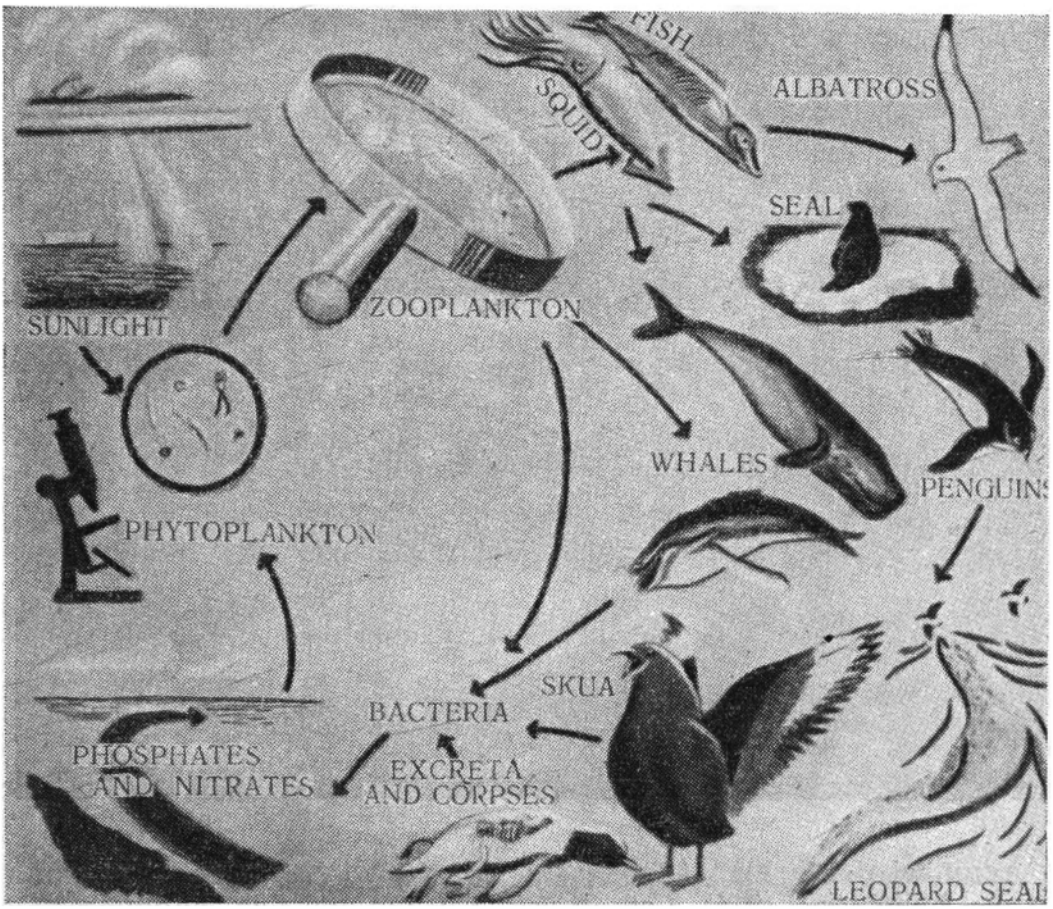
The main forms of zooplankton in the Antarctic seas are characterized by their slow vertical migration from the surface to deeper water and back. Many zooplanktonic forms are confined to comparatively narrow circumpolar belts of surface waters. This is due to the fact that these Antarctic belts possess more or less permanent characteristics (temperature, salinity, etc.). Depending on these characteristics and accustomed to definite conditions, the zooplankton try to maintain their distribution, but it is constantly disturbed by the currents.

How these minute animal organisms, which are almost incapable of moving horizontally, manage to remain in definite zones was a mystery until it was learned that they had worked out a clever method of fighting the currents by taking advantage of the circulation of the Antarctic waters.

In summer, these organisms drift northward in the surface waters, then descend to the southward-moving

water and return to the original spot. The descent in this case is between 400 and 600 metres deep.

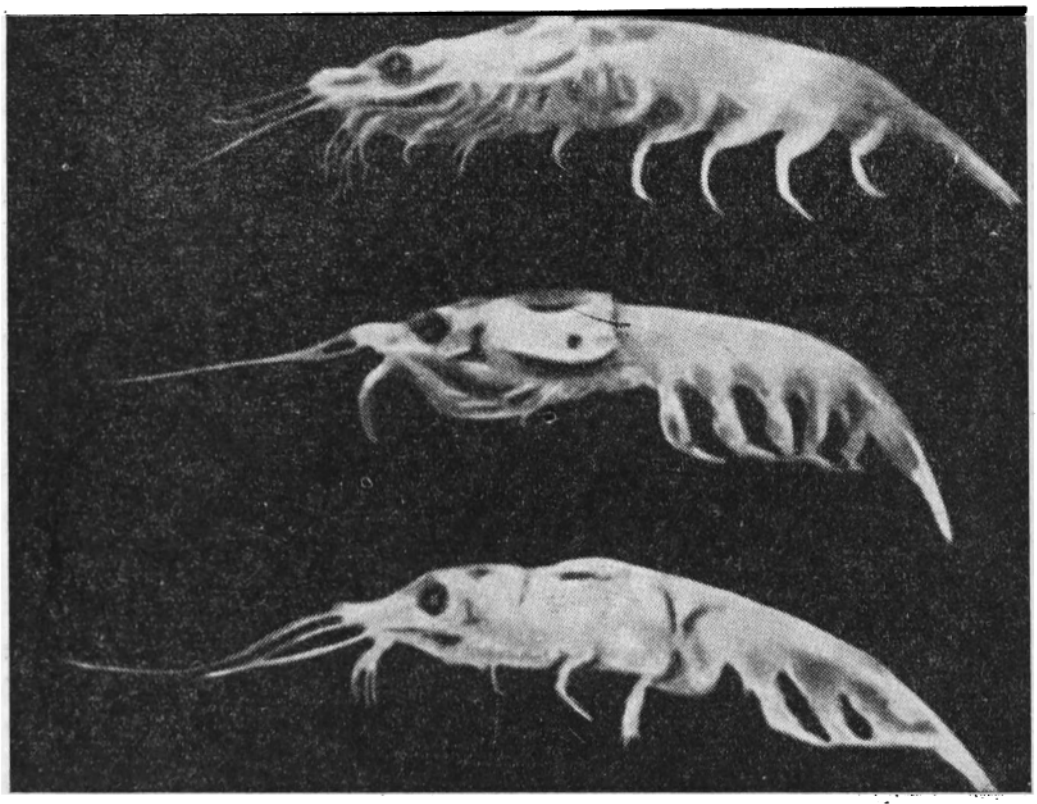
Such annual migrations, according to N. A. Mackintosh (1937) and R. K. Dell (1952) are performed in the Southern Ocean by the three dominant species in this



Cycle of life in the Southern Ocean (after Charles A. Fleming, 1952)

area—*Rhincalanus gigas, Calanus acutus* and *Eicronia hamata.* Other species have an energetic daily migration, remaining in the same belt. Some descend during the day and migrate to the surface in the night. It is therefore assumed that the plankton strive for a permanent amount of light during the 24 hours. It has also been learned that some species have no methods of maintaining themselves in the appropriate ecological niche.

The migration of *Euphausia superba* is evidently connected with its growth. F. C. Fraser (1936) has shown that in its earlier developmental stages the krills congregate chiefly in the southward-flowing warm deep water At the edge of the ice they rise to the surface together

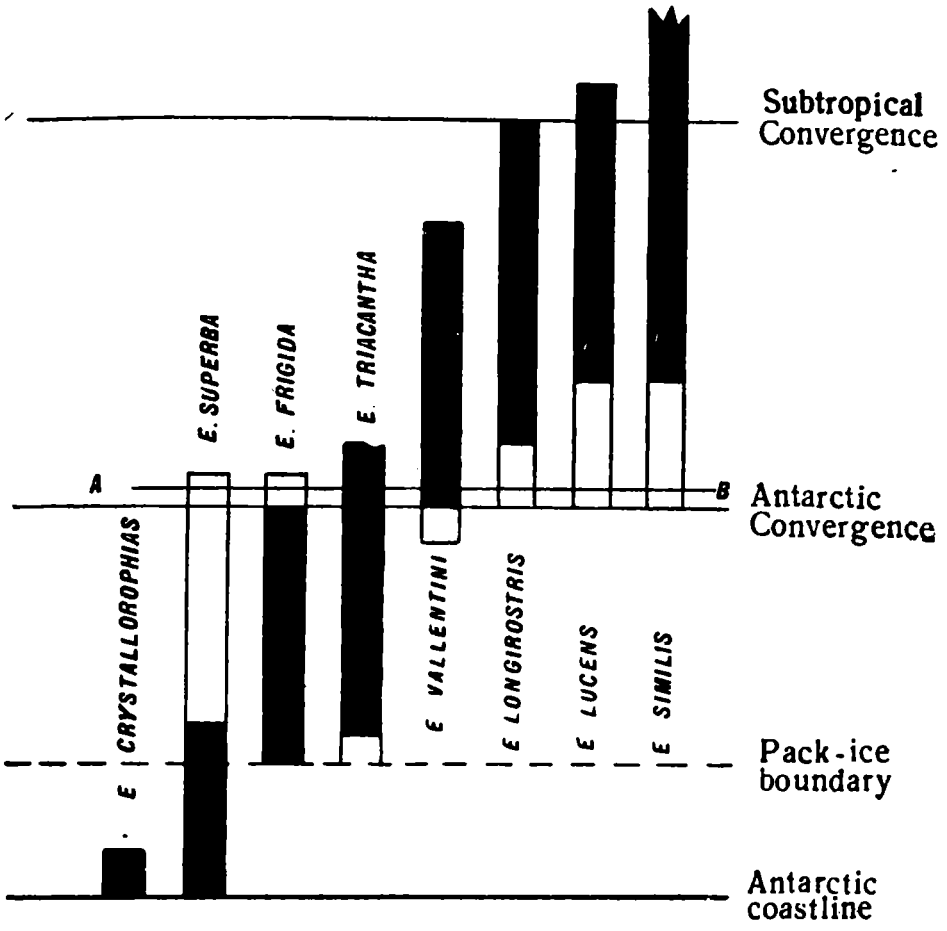


Adult whale "krills" (Euphausia superba) (V. A. Arsenyev and V. A. Zemsky, 1954). Length between two and five centimetres

with the vertical currents. The older species move in the opposite direction, northward, in the surface waters. Euphausia superba offer a graphic example of how various species adapt themselves to the characteristics of the water.

The scheme on p. 219 shows that of the eight species of the genus found in the Antarctic each is restricted to one zone and may be found outside it only in small numbers. The northern edge of the pack ice divides the An-

tarctic into two zones. Two species are found along the shores of the continent. One of them is *Crystallorophia,* which is confined more or less to the coastline, and *Euphausia superba,* which extends to the northern limits of the pack-ice. The other species occur in ice-free waters.



Distribution of species of Euphausia (after John)

This distribution of the plankton influences the distribution of other organisms feeding on the plankton. Such distribution patterns have been noted for the Southern Ocean birds by R. C. Murphy (1936).

The distribution of the algae is determined by the glacial conditions. The mighty ice-tongues descending the shores preclude the existence of sea-bottom plants. Ice shelves and land-fast ice hold back the light and prevent

the development of organisms. Off the shores free of glaciers one finds algae which provide shelter and food for a wide variety of sea animals.

The algae off the shores are very limited in the number of species represented, but abundant as individuals. The green, brown and red types have been studied very little as yet. The French expedition at Port Martin, in Adélie Land, found the species *Pelagos glandifolia* with leaves more than six feet long. There are altogether 44 types of algae in the Antarctic.

The waters off the shores abound also in sea urchins, starfish, crustacea, worms and many types of molluscs. Bottom-living fish appear to be plentiful. Scientists operating at Mirny caught twenty fishes, closely resembling bullheads, within a brief period.

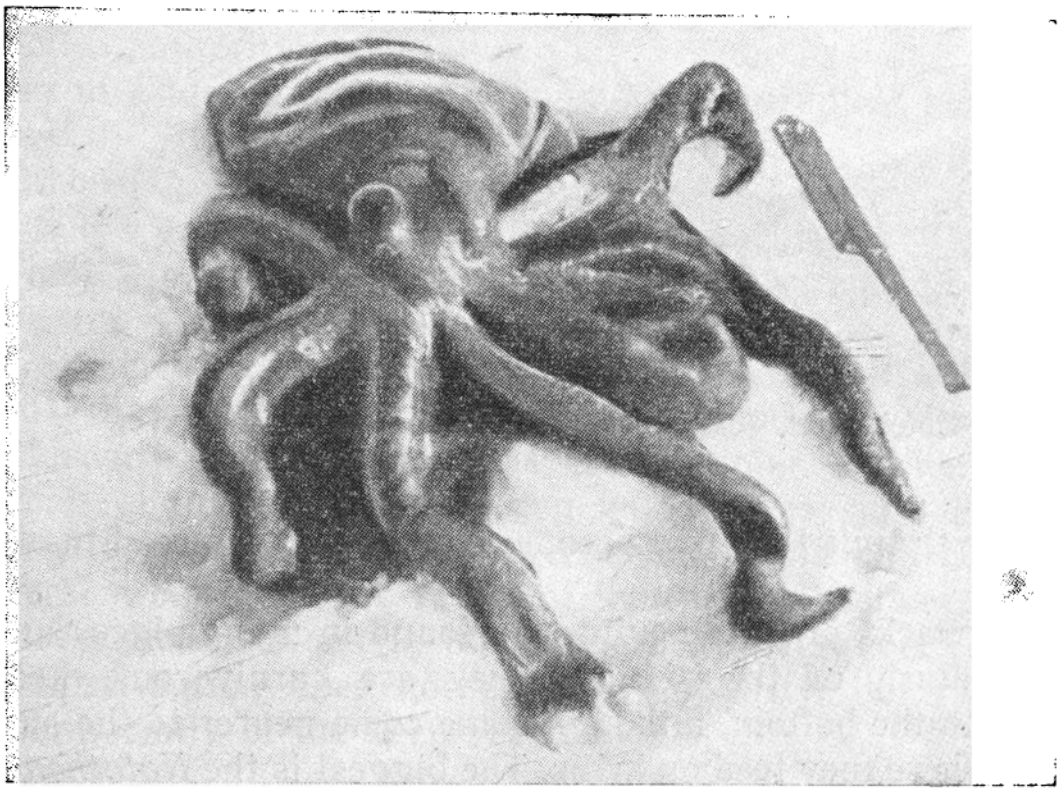
There are pterapods and an extremely large number of shell-fish. The latter are much more numerous than in the Arctic waters, and there are more sponges than in the equatorial parts of the Indian Ocean. In calm weather 30-centimetre-long jellyfish may be seen on the surface. Off the shores of some islands in the northern part of the Antarctic one comes across African-type lobsters. Resembling crayfish, they are from 50 to 60 centimetres long and live on rocky beds at depths ranging from 30 to 80 metres.

The cephalopods (that is, soft-bodied) are represented by species that differ both in size and appearance. Squids and octopuses are found in all waters whose salinity is not below 30‰.

Squids have well-proportioned elongated bodies with rhomb-shaped fins on the extremity and ten arm-like tentacles with suckers and claw-shaped hooks. They are found at all depths, from the surface to bottom waters. The smaller squids are from 0.25 metre to two metres in size, but the giant squids can be anything from 15 to 18 metres. Dawbin (1952) writes that the remains of the tentacles of 17-metre squids have been found in the stomachs of Cachalots. Octo-

puses have sack-like bodies that look sluggish at first sight and eight arms.

A close relative of our land snail, the squid is faster than any fish and for that reason it is often called "Sea Rocket." Squids prey not only on fish and crustacea, but

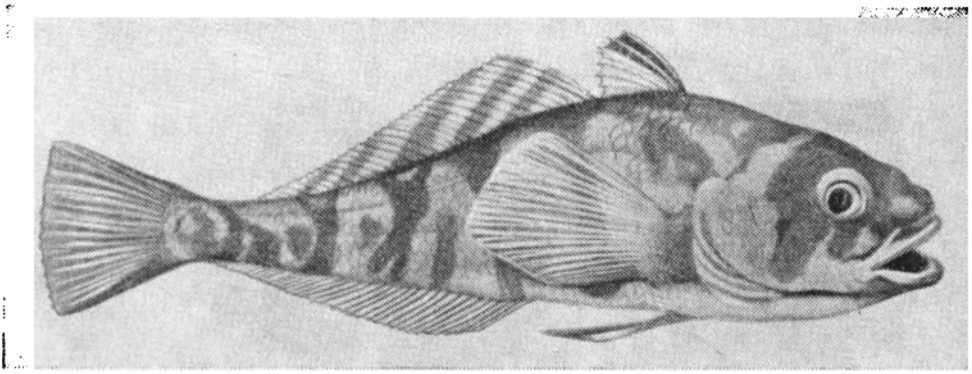


Antarctic octopus on ice (E. R. Mountevans, 1950)

on other molluscs and even on one another. Attacked by Cachalots, for whom they are the favourite food, they put up a terrific fight.

Many of the Cachalots taken have marks up to seven centimetres in diameter on the head and body left by squid suckers and even imprints of tentacles. That shows how immensely powerful squids are, for there has been a case when a Cachalot smashed the propeller of a ship without even scratching its head.

Ninety per cent of all the fish encountered in the Antarctic belong to the Nototheniid group, although they are extremely different in appearance. Some are very much like cod, others like roaches and still others like bullheads. Most of the Nototheniids are edible and it is quite possible



Nototheniid, dominant fish in the Antarctic (Erich von Drygalski, 1904)

that with time they will become an important item of man's diet.

Big packs of Nototheniids are found in many places and particularly off the islands. They are carnivorous, keep close to the bottom, although some come nearer to the surface where they feed on krills. The biggest is the *Notothenia Rosii*, which is one metre long and is encountered chiefly off South Georgia and the South Shetlands. The Nototheniids are divided into three groups in accordance with the sectors in which each predominates: The Falkland sector, the sector of the Kerguelen and Macquarie sector and the sector stretching from New Zealand to the Falkland Islands. Most of the other fish in the Antarctic belong to the *Zoarcidae* group, which is also met with in the Northern Hemisphere waters.

The ichtyofauna of the Antarctic has been studied very little so far, for the above-mentioned groups are of little economic value, while systematic scientific surveys are almost non-existent.

Scientists studying the polar regions of the globe have discovered close relationship and even similarity between certain organisms which occur in the Arctic and Antarctic, but not in the moderate and warm latitudes.

This phenomenon is called bipolarity and it is explained by a number of theories, each of them valid in its own way.

Some authorities presume that bipolar animals are relics of a former cosmopolitan fauna, the tropical portion of which is now extinct.

Others say that parallel independent development in the two areas may have resulted in apparent identity.

There is also the opinion that certain organisms may have migrated from one polar region to the other through the cold deep-water regions of the tropics. A.W.B. Powell (1951) has supplied evidence of the method by which the molluscan genus *Aforia* achieves a bipolar distribution. Species of this genus have been found at various depths near Alaska, Siberia, Japan, Kerguelen Island and in the waters in-between. The range of temperature between all the recorded stations is 6°C. Others say, however, that this distribution does not explain bipolarity, but rather the uniformity of the deep sea fauna.

ACTIVITIES TODAY

In our days of colossal technological opportunities and hitherto unparalleled development in meteorology, geology, oceanology and other sciences, there is growing world-wide interest in the study of the lifeless south polar expanses.

In the Soviet Union, Antarctic research is carried on by a number of institutes under the direction of the U.S.S.R. Academy of Sciences and the North Sea Route Administration. The *Slava* whaling flotilla began operating in 1946. Geographical and biological problems of the Antarctic are studied by the U.S.S.R. Scientific Research Institute of Fishery and Oceanography of the Ministry of Fisheries, the State Oceanographic Institute of the Hydro-Meteorological Services Administration of the U.S.S.R Council of Ministers, and the Geographical Department of Moscow University. These institutions have published a number of works on Soviet biological, oceanological and meteorological research in the Antarctic.

In Britain, Antarctic activities are co-ordinated chiefly by the Scott Polar Research Institute, set up in 1925 with funds contributed for the support of the dependents of Robert Scott and his companions who perished in Antarctica. For more than twenty years now the Institute has been publishing the *Polar Record* and a bibliography of recent polar literature reviewing nearly 300 journals. The Royal Geographical Society issues the *Geographical Journal* which reviews Antarctic works by all well-known au

thors. The Society shared in the Norwegian-British-Swedish (1949-52) and other Antarctic expeditions. Also engaged in south polar research is the National Institute of Oceanography which publishes scientific material on Antarctica in its *Collected Reprints.*

In the United States, the Antarctic region is studied chiefly by the American Geographical Society and the Smithsonian Institution in Washington. These two organizations have taken part in numerous Antarctic expeditions and publish works on Antarctica in the *Annual Reports of Smithsonian Institution* and the *Geographical Review.* The American Polar Society publishes the twice-yearly *Polar Times* carrying diverse information on the polar regions.

Then there is the New Zealand Antarctic Society which issues the quarterly *Antarctic News Bulletin* carrying the latest information on the activity of scientific expeditions, whaling, etc. In 1952, the Society published a collection of scientific works under the title of *The Antarctic Today.* Articles about Antarctica are also published by the *New Zealand Geographer.*

Major research in recent years has been carried on in the area of Adélie Land by the Expeditions Polaires Françaises.

The Antarctic Australian Research Expedition (ANARE) set up permanent stations on Heard Island (1948) and in MacRobertson Land (1954). Some of the results of Australian Antarctic research are published by the Royal Geographical Society of Australasia in the *Proceedings of the Royal Geographical Society of Australasia.*

Other organizations doing Antarctic research include the Instituto Antarctico Argentino (Buenos Aires), the Norsk Polarinstitut (Oslo) and the Deutsches Hydrographisches Institut (Hamburg). New data on the Antarctic are being obtained in the investigations provided for by the programme of the International Geophysical Year.

The programme was drawn up by the Paris and Brus-

sels sessions of the IGY Preparatory Committee. The Soviet programme includes the study of the influence exerted by atmospheric processes in the Antarctic on general air circulation on the Earth, fundamental problems of the movement of Antarctic waters and their connection with the circulation of water in other oceans, geological structure and history of the bottom relief in the Antarctic region, Antarctic ocean glaciology, currents in the south polar basin, raw-material base of Antarctic whaling, zonal distribution of fauna in the oceans, present-day ice-sheet of Antarctica and its dynamics. Moreover, the programme provides for physico-geographical charting and description of Antarctica, compilation of geological and historical data on the Antarctic region and investigation into the geophysical and biogeographical peculiarities of Antarctica.

Observations and collection of data will be carried out by some 50 stations to be set up by 13 countries in various parts of the continent.

The Soviet Antarctic expedition began its preliminary operations in the Indian sector of the Antarctic in January 1956. It was sponsored by the North Sea Route Administration of the U.S.S.R. Merchant Marine Ministry, an organization with rich experience in Arctic research, and dozens of other institutions. Scientific direction is in the hands of the U.S.S.R. Academy of Sciences. The expedition is headed by Hero of the Soviet Union M. M. Somov, D. Sc. (Geography), deputy director of the Arctic Scientific Research Institute of the North Sea Route Administration. In 1950-51, he directed the activities of the North-Pole Drifting Station No. 2. The expedition consists of over 200 scientists of various specialities, about 300 seamen, and flyers, builders and technicians.

The expedition has two diesel-electric sister-ships *Ob* and *Lena,* especially equipped for oceanographical, hydrobiological and other survey operations. They displace 12,600 tons, have a freight-carrying capacity of 6,160 tons, and

Mikhail Somov, head of the Soviet expedition

engines of 7,000 h.p. They are 130 metres long, develop a speed of 15.5 knots an hour and can sail 15,600 miles without refuelling.

Ninety-two scientists of the expedition wintered in Antarctica in 1956.

The main Soviet scientific station in Antarctica, the South Polar Mirny Observatory, was opened on February 13, 1956. It is situated on the shore of the Davis Sea, near the Haswell Islands, in 66°33′S., 93°E.

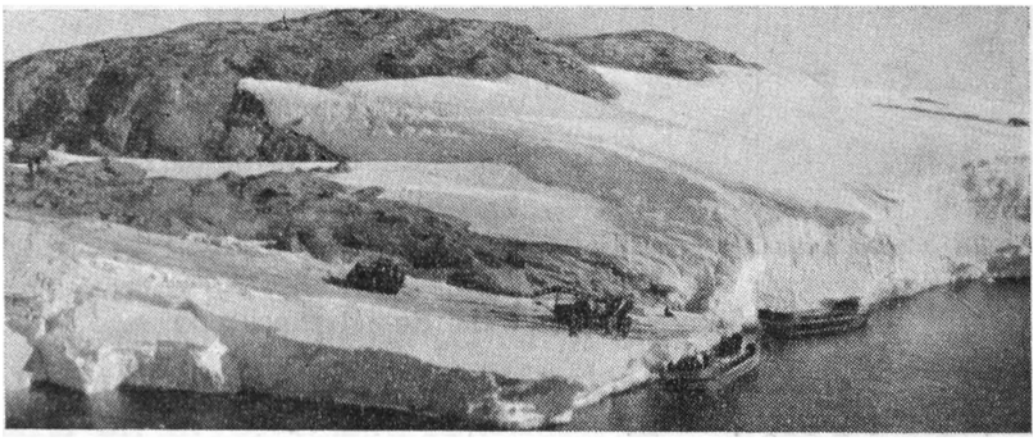
The observatory has magnetic, seismological and aerological pavilions and geophysical, aerological, geological, glaciological, gravimagnetic, aerophotogrammetric and photographic laboratories with up-to-date equipment and instruments.

The party wintering in 1956 set up two more stations, one on May 27 and the other on October 15. The former, Pionerskaya, is in the interior about 2,700 metres above sea-level and has a team of six men. It is 375 kilometres

from Mirny, in 69°44′S., 95°30′E. The latter, Oasis, with a staff of three, is situated in 66°16′S., 100°44′E.

The Pionerskaya team have made meteorological, actinometric and aerological investigations and studied snow accumulation and the dynamics of the snow cover.

Apart from regular meteorological work, the Oasis station has been doing actinometric, gradient and special wind observations.

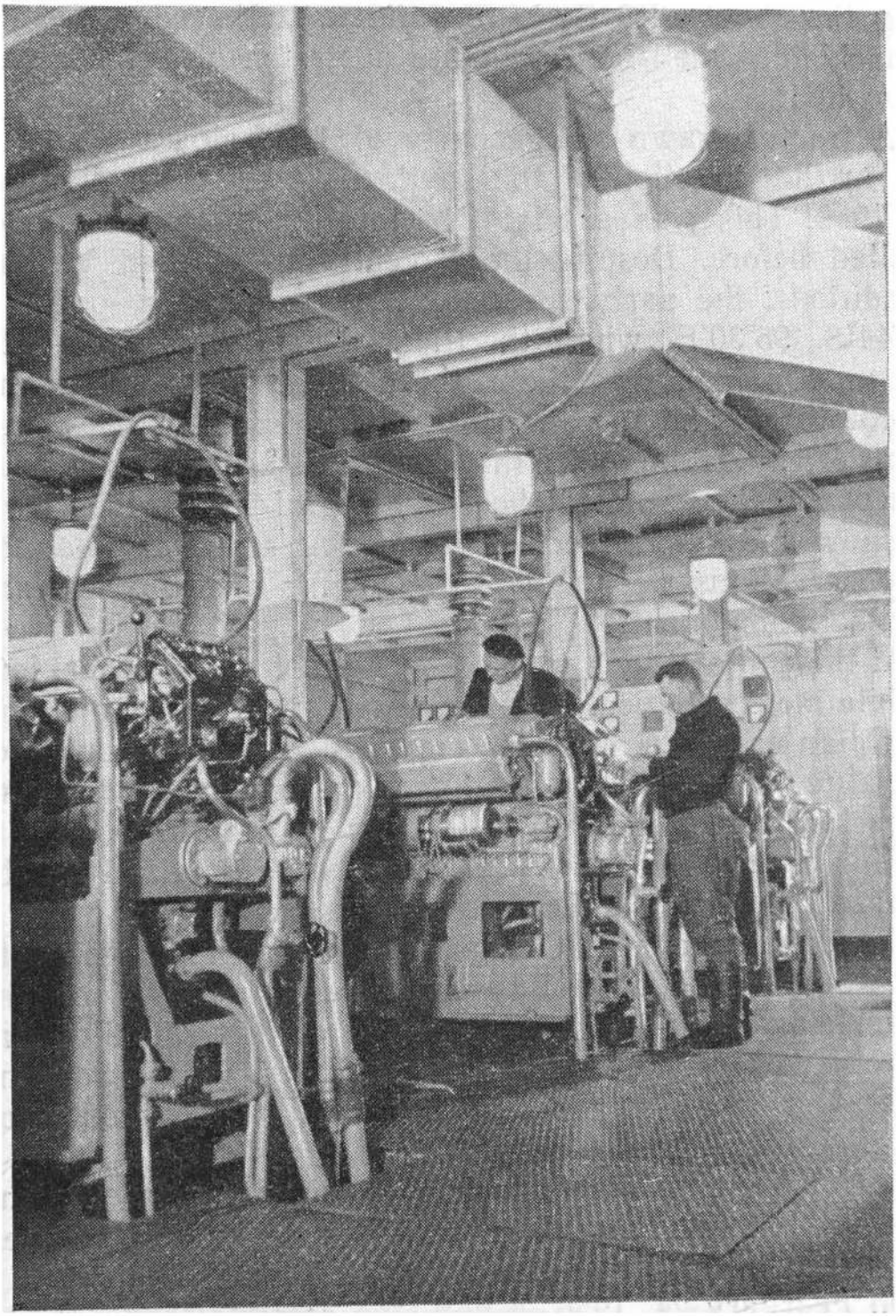


Unloading at Mirny (Soviet Antarctic expedition, 1956)

Scientists started working immediately on their arrival in Antarctica, setting up first a network of astronomical stations and organizing aerial photography, both of which were to serve as a foundation of all research envisaged by the plan.

An area of more than 15,000 square kilometres, stretching along the coast from Mount Gauss to the Shackleton Shelf-Ice and thence along the coastal protuberance off the shelf-ice to and including the Bunger Oasis, was photographed from the air in January 1956. The total length of the itinerary was about 2,000 kilometres.

More photographs from the air, similarly of an area of upwards of 15,000 square kilometres, were taken in October and November of the same year. The objects this time were the Mirny-Depot Bay area, the Bunger Oasis (pho-



The Mirny power station

tographed for the second time for the purpose of comparing the shots with those of January), the edges of the Shackleton Shelf-Ice and quite a stretch of the coastline east of it.

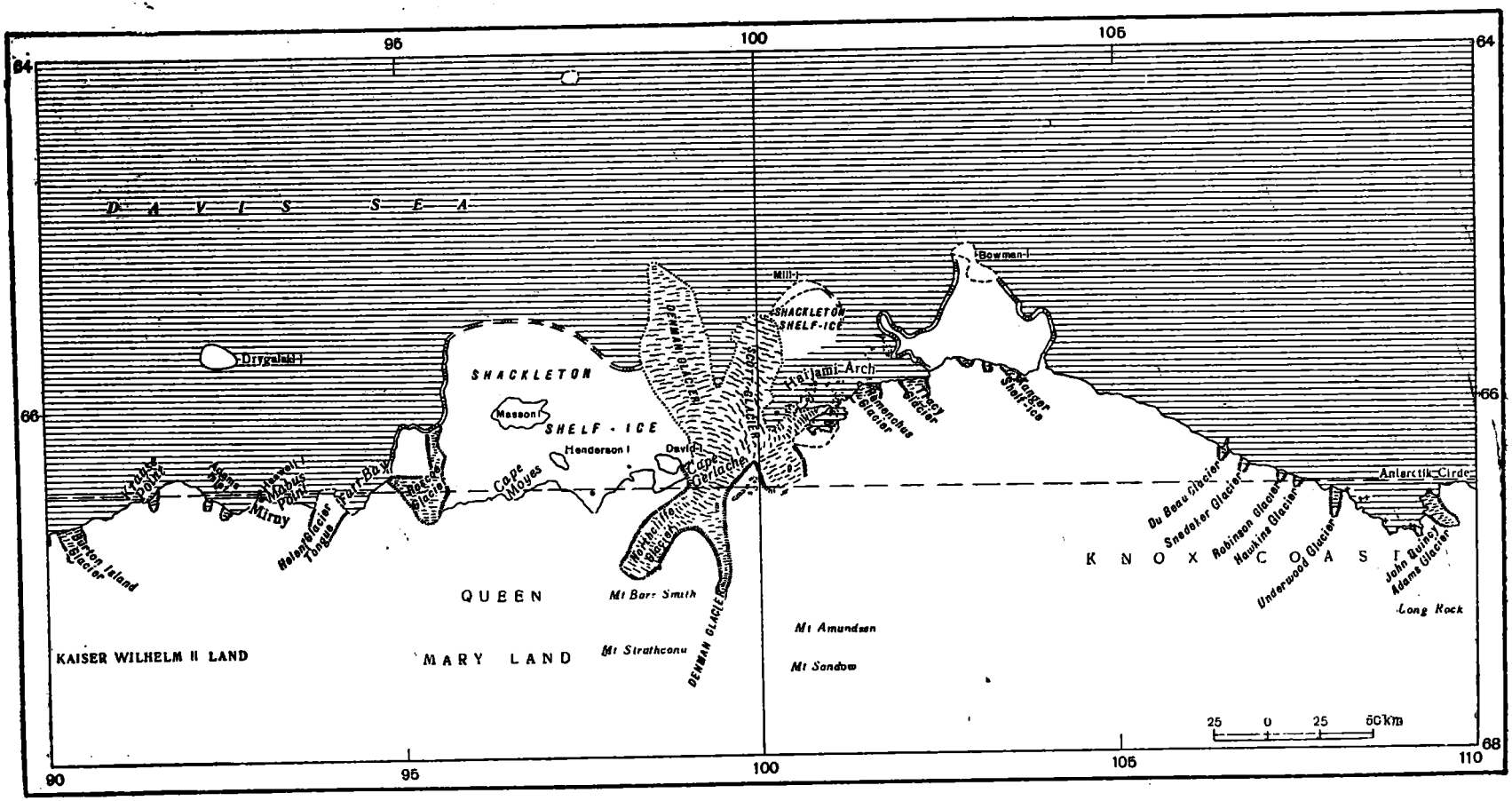
A tractor-drawn sledge party of 11 explorers left Mirny in the direction of the south magnetic pole on April 2, 1956. This was a trial trip into the hinterland never visited before. Despite the difficult late-autumn weather conditions, the party succeeded in reaching a point in 69°44′S., 95°30′E., where the Pionerskaya station was later set up. On their way there, the explorers carried out meteorological and aerological observations, with planes from Mirny taking part in aerological soundings. Simultaneously, they studied the character of the surface layer of snow and determined its density. At stopovers magnetic observations were made of gradients of horizontal and vertical components.

At the end of July and early in August of that year, four mobile meteorological stations were set up along the 93rd meridian east of Greenwich, on the sledge-party route, for the study of local, or glacial. winds which play a very important role in the Mirny area, and of the microclimate of this area. Some interesting data were obtained on the winds in this part of East Antarctica.

Towards the end of October a dog-drawn sledge party left Mirny for Depot Bay and thence north along the Shackleton Shelf-Ice. In the course of this 240-kilometre trip the explorers collected ice samples for subsequent laboratory analysis and took notes on twelve profiles of the shelf-ice edge.

In October and November Soviet explorers surveyed the Grierson Islands, lying off Knox Land some 800 kilometres away from Mirny, and the coastline in the vicinity.

On February 24, 1956, a non-stop reconnaissance flight was made to the south magnetic pole, and a similar flight was undertaken on March 3, in the direction of the pole of inaccessibility, to 78°S.



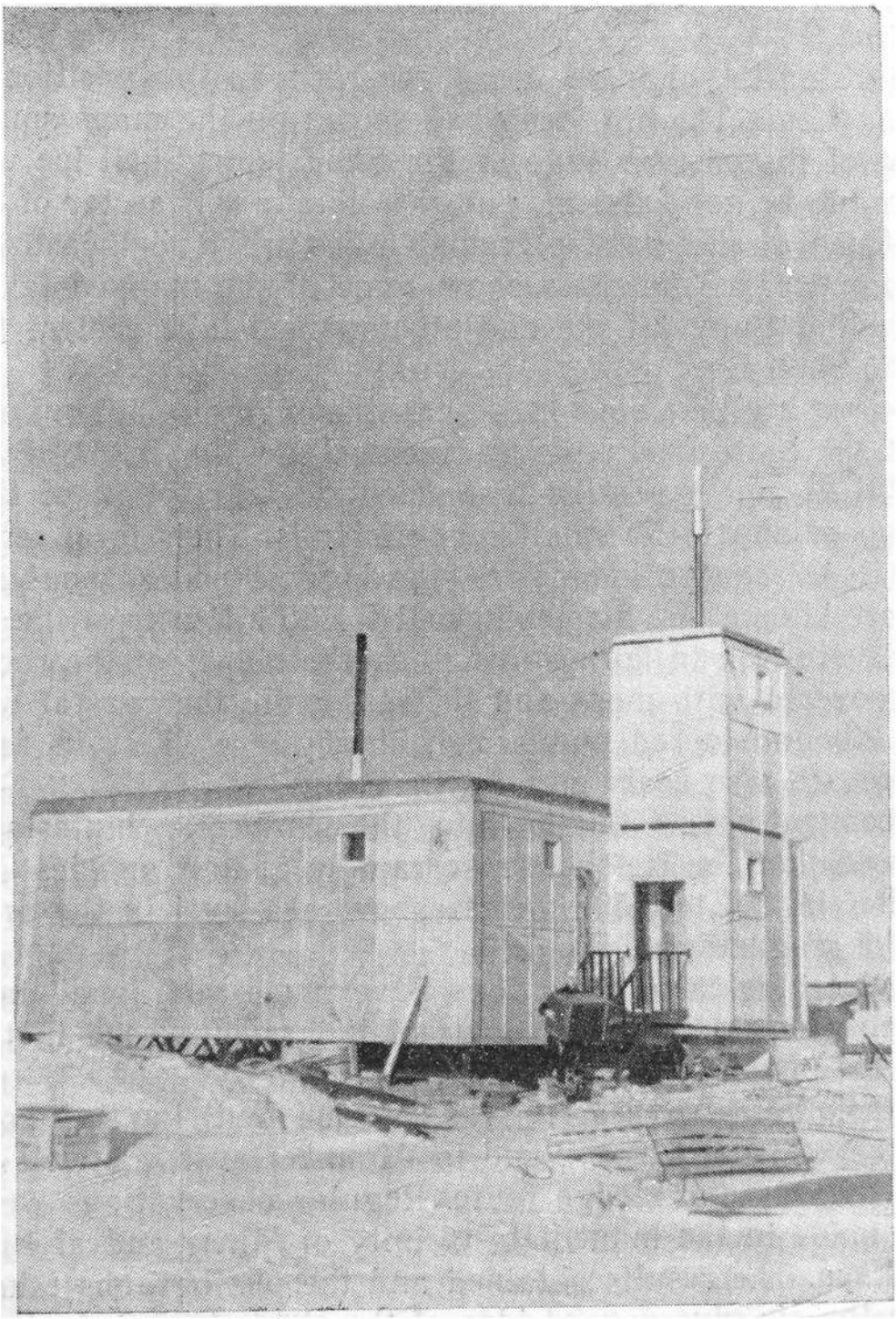
The Antarctic coast in the Indian Ocean

To study the ice of the Davis Sea and in the southern part of the Antarctic Ocean, Soviet explorers made 22 reconnaissance flights and obtained data on the position of the northern ice boundary in the sector lying between 80° and 100°E., as well as on the general drift of the icebergs.

The very first surveys enabled Soviet explorers to particularize and correct the existing Antarctic maps and chart the coastline. A part of one of these charts, embracing the coast between 90° and 110°E., is published on p. 231. It gives a pretty good idea of the general outlines of the little-known part of Antarctica in the areas of the Davis Sea, Shackleton Shelf-Ice and Knox Land, and corrects some of the gross mistakes in earlier maps. Astronomical and geodesical observations reveal that the coastline within the Shackleton Shelf-Ice is much more to the north than shown in those maps. Mill Island should be displaced about 30 miles to the southwest and so should the northeastern edge of the Shackleton Shelf-Ice.

New scientific data were also obtained in the survey of the Bunger Oasis. Its territory, constituting part of the East-Antarctic platform, is formed of gneiss and granite. Surveys made at certain depths towards the end of the summer melting season showed there were frozen rocks there. That completely refutes earlier assumption that the oasis was created by the heating of the surface by underground heat sources (volcanoes, radioactive decay or subterranean coal fires).

The surveys confirmed the opinion held by some that the formation of the oasis was due to topographical and meteorological phenomena, firstly, to glacierization action from the interior, facilitated by the relief of the area, and, secondly, to the denudation of many sectors by wind action. The latter considerably alters the temperature on the surface with the result that ablation predominates over the accumulation of snow on the entire territory of the oasis. Soviet explorers' description of the oasis shows that it is



Explorers' living quarters at Mirny

dotted with low hills, conical in form and between 60 and 90 metres in height, though some are as high as 180 metres.

Substantial changes were recorded in the position of Knox Land. The big, deep bay shown on the maps southeast of the eastern edge of the Shackleton Shelf-Ice was found to be non-existent. The coastline in this sector of the continent should be displaced 45 miles to the northeast. Air reconnaissance failed to show some of the mapped lakes, including Bunger Lake and an unnamed lake east of the Scott Shelf-Ice.

Surveying the Grierson Islands, the explorers determined that the central part of the archipelago lay in 66°18′S., 110°31′E., and gave the first scientific description of this group of about 150 small rocky islands. Their total territory is 25 square kilometres, the biggest being about six square kilometres. Stretching out for 30 kilometres, the islands are rich in flora and fauna—the slopes of the rocks are covered with moss and lichens, while the coastal waters abound in red and brown algae, as well as in fish. There are also seals and Adélie Penguins.

Reconnaissance flights into the Antarctic hinterland showed that the ice-sheet rose rapidly at first and less so farther inland to 3,500 metres above sea-level in the area of the magnetic pole in 78°S.

Meteorological observations gave much additional data refuting original claims. Some of it was discussed in the chapter on meteorology above.

Glaciological research was carried out in the area stretching from Knox Land to Mount Gauss, as well as along the tractor-sledge route. Regular observations were also made in the immediate vicinity of Mirny and at Pionerskaya. The results obtained and the photographs taken from the air give a good idea of the character of glacierization in this part of Antarctica. It was determined that ice streams moved from a few inches to several dozen centimetres a month. The explorers measured the thickness

of the ice-sheet between Mirny and Pionerskaya, surveyed its structure and analyzed many ice samples obtained from different layers in icebergs, excavations and crevasses.

New data were obtained by the oceanographic party headed by Professor V. G. Kort, which left on its survey voyage aboard the *Ob* on February 29, when the construction of the Mirny Observatory was nearing completion. The party carried out oceanographic research in the Antarctic waters in the area between 91° and 162°E., in the sector from the Balleny Islands to New Zealand via the Tasman Sea, and from Australia to the Davis Sea. The *Ob* completed her scientific cruise and returned to Mirny in May.

After the Davis Sea the expedition made surveys in the Indian Ocean. Deep-water observations were completed at the entrance to the gulf of Aden on June 8. Investigations were made at 156 deep-water oceanographic stations. In the Antarctic, the *Ob* skirted Knox Land, Sabrina Coast and Côte Clarie. The expedition visited the islands near Sabrina Coast and made observations there. They are formed of volcanics—granodiorites and gabbro, criss-crossed in a number of places by pegmatitic lodes. Depth measurements in the Davis Sea revealed that there were two banks and a deep dividing them. These banks are apparently morainal faults resting on tectonic folds and stretching parallel with the ice barrier across the whole of the Davis Sea and then continuing farther to Côte Clarie (135°E.). The northern boundary of these faults coincides in the main with the edge of the barriers in places where they protrude most into the ocean. The outer faults presumably formed in the period of glacial maxima. Coastal morainal faults are in line with the edge of present-day mainland glaciers. The expedition made observations at 57 oceanographic stations in the Antarctic coastal waters and established that the entire shelf of the surveyed region may be the zone of Antarctic water formation provided there is a small advective influx of heat.

North of the shelf boundaries, the Antarctic waters form

a strip 20 miles wide and flow along the continental slope to a depth of 1,000 metres.

Investigations of the Kerguelen-Gaussberg Ridge brought substantial correctives into its morphological structure. Valuable data were collected in this region by the geologists of the expedition.

Vladimir Kort is in change of hydrological survey

The second Soviet Antarctic expedition is on an even bigger scale.

The unloading of vessels was begun at Mirny on December 17, 1956. One hundred and sixty-eight persons remained to winter on the continent. In March 1957, the expedition set up a new station—Vostok-I[1]—inside the continent, more than 650 kilometres from Mirny, and made preparations for the establishment of the Komsomolskaya Station at the 860th kilometre. This station, 3,500 metres

[1] The station was opened on March 17, 1957, in 72°S., 96°30′E., as an intermediate base and was closed in November of the same year.

above sea-level (in 74°5′S., 97°29′E.), was opened on November 6, 1957. It will make meteorological surveys as provided for by the International Geophysical Year programme. In addition, it is intended to play the role of an intermediate base for the Soviet expedition's advance towards the south magnetic pole.

Two mobile scientific stations—one on the route to the magnetic pole (78°S., 170°E.) and the other on the way to the pole of inaccessibility (82°S., 60°E.)—began operating towards the end of 1957. The Vostok Station in the area of the south magnetic pole was opened on December 16, 1957, and the Sovetskaya Station (78°34.5′ S., 87°35′ E.) was opened on February 9, 1958. On December 14, 1958, Soviet explorers reached the pole of inaccessibility in 82°06′ Lat.S., 55° Long.E. and set up the pole of inaccessibility scientific station.

On their second expedition, the oceanographic vessels *Ob* and *Lena* carried out large-scale survey operations along the continental coast, from Mirny to 20°E.

The Soviet Antarctic expedition had two scientific-research vessels and fourteen aircraft at its disposal.

Apart from the Soviet Union, there were 12 other countries (the United States, Britain, New Zealand, France, Japan, Australia, Argentina, Norway, Chile, Belgium, the German Federal Republic and the Union of South Africa) that planned to participate in surveying the Antarctic region during the International Geophysical Year.

The first nine, according to press reports, set up their stations in the course of the 1956-57 Antarctic summer. Belgium and the Union of South Africa set up their stations later on. According to press reports, the despatch of the German Federal Republic's expedition is being held up chiefly by financial difficulties.

The biggest of these expeditions was the American, whose programme provided for the establishment of seven scientific bases in different parts of the continent and one service station to fuel planes flying to the South Pole.

The American bases were built by the Navy, Air Force and Army.

U.S. activities in the Antarctic were given the name of "Operation Deepfreeze." During the 1955-56 season the Americans carried out "Operation Deepfreeze I" and "Operation Deepfreeze II" in 1957. Both of them were directed by Vice-Admiral George Dufek, who had taken part in many of Byrd's expeditions. Byrd himself was in charge of the entire Antarctic programme until his death at the age of 68 in March 1957. Survey work was directed by Dr. Paul Siple.

The IGY preparatory phase was rounded out by "Operation Deepfreeze II."

In 1955-56, the Americans succeeded in setting up only two stations, Little America on the Ross Barrier in Kainan Bay (78°16′S., 162°28′W.) and an air base on Ross Island in McMurdo Sound, instead of three (the third Byrd Base in Marie Byrd Land).

Construction of the remaining stations was begun in the early Antarctic spring of 1956. The first item on the programme was the South Pole station, which was completed in December of that year and named the IGY Amundsen-Scott South Pole Station. The 18-man party wintering there is headed by Dr. Siple. Half-way between the South Pole and McMurdo Sound the Americans built a refuelling station at the foot of the Liv Glacier. At the time the South Pole station was under construction, it was staffed by seven men.

The Americans completed their fourth station, on Cape Hallett, in Queen Victoria Land in the Ross Sea, early in February 1957. Survey work there is carried out jointly by American and New Zealand scientists and for that reason it is usually called joint American-New Zealand station. Its staff numbers eleven.

Of the seven American bases only two are in the interior: the South Pole and Byrd stations. The construction of the latter required great efforts. The most serious difficul-

ties fell to the lot of the eleven-man advance party who had to negotiate a badly-crevassed expanse. Travelling in weasels and operating with the aid of a helicopter and an electronic crevasse-locator, they hewed a 632-mile route from the Little America Base V to 120°E., 80°S., completing the journey by December 18, 1956. The first team was

A helicopter takes off from the *Lena* (Soviet Antarctic expedition)

followed by two sledge parties with six tractors. The wintering party consisted of 25 men.

The programme for the 1957-58 summer season envisaged large-scale research work at the Byrd Base. According to plans, it was to be connected by overland routes with the Roald Amundsen Sea, the Bellingshausen Sea, the centre of the Lassiter Shelf-Ice (in the Weddell Sea) and Vahsel Bay.

During the 1956-57 season the Americans also built bases in the Weddell Sea, in 77°45′S., 41°W. (in the area of Bahia Chica Bay), and in Knox Land, in 66°35′ S., 109°E. (on the Windmill Islands in Winseness Bay).

Adverse glacial conditions during this season threatened to nullify the effort to set up these two stations, and the situation was saved by the powerful icebreakers *Glacier*, *North Wind* and *Staten Island*.

Conditions proved especially difficult in the Weddell Sea. The transport *Wyandot* and the *Staten Island* got caught in close pack-ice on their way to the southern shore of the

The Mirny Observatory messroom

Weddell Sea, where the Ellsworth base was to be built, and both sustained damage. They succeeded in breaking out only a month later and it was then decided to build the base in Bahia Chica Bay, 800 miles east of the originally planned site. The scientific section of the expedition is headed by the well-known Antarctic explorer Finne Ronne. Ten scientists are wintering at this station.

The difficulties experienced by the vessels *Arneb* and *Glacier* in approaching the planned site of the Wilkes Station in Knox Land were just as great. After repeated attempts to break through to the Windmill Islands from dif-

ferent directions, the *Glacier* finally reached them along the 109th meridian. The transport *Arneb,* with a twisted screw and a gaping hole (she suffered the damage in the Ross Sea), limped badly behind the icebreaker. A scientific party of 27 men will remain at the station for two years. The expedition is headed by Carl Eklund, the well-known American scientist.

"Operation Deepfreeze II" ended on February 20, 1957. Taking part in it were 3,500 men of the U.S. Navy and Air Force, twelve vessels and forty aircraft. The wintering party in Antarctica numbers 338, half of them scientists and the remainder Army service personnel. According to Vice-Admiral Dufek, the American Antarctic bases cost $30,500,000 to put up, transport charges excluding.

Britain has many scientific stations in Antarctica, but, unlike the American bases, they are concentrated in a comparatively narrow sector: ten in Graham Land and on the off-lying islands, and two in the Weddell Sea. The meteorological stations in Graham Land are permanent and their construction was begun way back in 1940.

Two new stations were set up on the shore of the Weddell Sea during the 1955-56 season. The geophysical station in Halley Bay (75°30′S.), established by the Royal Geographical Society, will operate only during the International Geophysical Year. The other is the Shackleton Base, set up by the Transantarctic expedition in Vahsel Bay, 200 miles to the south.

A relief wintering party (and the main party under Dr. Vivian Fuchs for the Shackleton Base), foodstuffs and equipment for the two new stations arrived in Halley Bay aboard the *Magga Dan* on January 8, 1957.

It was from the Shackleton Base that a 14-man party headed by Dr. Fuchs had to leave on its trip to the South Pole (November 1957-January 1958) and thence to McMurdo Sound (February-March 1958). To help them, a group of New Zealand polar explorers, headed by the well-known mountaineer Edmund Hillary, planned to leave their Scott

Base in McMurdo Sound. The two parties, which had to meet at the South Pole, decided to take skis and dogs along and were prepared to abandon their weasels if the crevasses should prove unnegotiable, for south of the Shackleton Base the ice-cap is full of them. Moreover, 100 miles from the base rises a mountain range with peaks of 1,500-1,800 metres. It was discovered from the air in 1955 and its length is unknown.

The main object of the British and New Zealand expeditions was to set up intermediate bases along the route, at a distance of about 250-300 miles from the main stations. A British party of four men remained at their intermediate base to carry on with survey work from April to December 1957. The man in charge was H. Lister, the well-known glaciologist.

The Transantarctic expedition's job envisaged large-scale observation, one of the items being the measurement of the ice-sheet every 30-40 kilometres. For 200 miles from the British intermediate base the Fuchs party was supplied from the air. The remaining 300 miles to the South Pole it covered without outside assistance, except for the information on the state of the route it received from planes.

Difficult glacial conditions prevented the New Zealanders from setting up the Scott Base at the foot of the Ferrar Glacier, as originally planned. The expedition vessel *Endeavour* unloaded her cargo on Ross Island off Cape Pram, and it was there, near an American station, that they set up their base. There are two parties working there now. One of them, headed by Dr. Trevor Hatherton, is engaged in IGY survey. The other, led by Hillary, is an auxiliary unit of the Transantarctic expedition.

A reconnaissance party with three dog teams left the Scott Base on January 13, 1957, to mark the way to the Ferrar Glacier, set up a store there and, conditions permitting, to continue farther south to a distance of about 300 miles from the Scott Base. It was supplied with foodstuffs from the air, and was followed by two tractors with provi-

sions and equipment. On the way back the party carried out geological observations and mapped the western slopes of the little-known mountain ranges in Queen Victoria Land.

The French expedition was organized by the Antarctic Sub-Committee of the French National IGY Committee. A winter party of fourteen, headed by Robert Guillard, landed on Pointe Géologie in Adélie Land on January 1, 1956, and set up their headquarters at the old Dumont d'Urville base, which was abandoned several years ago.

The expedition has completed the Charcot Station in the area of the south magnetic pole, 300 miles from the Adélie Land coast. It is staffed by three men.

The 1955-57 party, which had built two bases, was relieved in 1957 by a group headed by Bertrand Imber, deputy leader of the 1950-52 Adélie Land expedition. This group arrived in the *Norsel* with 350 tons of foodstuffs and equipment.

The Japanese Antarctic expedition, headed by Professor Takesi Nagata, arrived in the icebreaker *Soya* on January 29, 1957, and landed on Ongul Island in Lutzow Bay off Prince Harald Land. The expedition's base is in the vicinity of 40°E. and the wintering party consists of eleven men. Transport facilities include two helicopters and several tractors.

The Australian Mawson Station in MacRobertson Land (62°53′E., 67°37′S.) was opened in 1954 and has been doing research work ever since. The staff consists of 24 men and they have two light planes at their disposal.

Early in 1957 the Australians completed the Davis Station east of the Mawson base in Ingrid Christensen Land (68°33′S., 77°56′E.). It has a staff of five men.

On the Windmill Islands (66°20′S., 110°15′E.) the Australians set up an automatic meteorological station which registers pressure, temperature, relative humidity, and the velocity and direction of the wind.

Prior to 1957 Chile had three scientific-research stations

in Graham Land. The work is done mainly by the Chilean Navy.

Four Chilean warships lay off the Antarctic coast for four months during the 1956-57 season.

One of the main jobs of the expedition was to build an airfield on Roberts Island (South Shetlands) to service the planes of the Antarctic expedition. This airfield is on the Punta-Arenas—Weddell Sea base—South Pole line and, like the new scientific station off the coast of Graham land (where a party of ten scientists is wintering), it represents Chile's main contribution to the IGY. At present Chile has four stations in Graham Land.

Argentina had to set up nine stations for the IGY, eight of them in Graham Land and the ninth, the General Belgrano Station, on the Lassiter Shelf-Ice in the Weddell Sea, 35 miles from the American Ellsworth Station (77° 45′S., 41°W.).

The Norwegian Antarctic expedition sailed from Oslo in two whalers, the *Polarsirkel* and the *Polarbjorn*, in November 1956. Headed by Sigurd Helle, a geodesist of the Norsk Polarinstitut, the expedition is 14-strong and set up a station in Queen Maud Land (2°32′W., 70°30′S.).

The Belgian Antarctic expedition began operations during the 1957-58 season in 70°26′S., 24°18′6″E., that is, between the Norwegian (2°E.) and Japanese (39°E). bases.

The Belgian expedition is headed by Gaston Gerlache, the son of the leader of the *Belgica* expedition of 1897-99, which was the first to winter in Antarctica.

Dr. Herligkoffer, organizer and leader of the German expedition, said the German base in Antarctica would be located in 7°W. The expedition, however, has not left for Antarctica. It plans to continue the work started by the *Schwabenland* expedition in 1939.

The Soviet Antarctic expedition maintains friendly scientific contact with many other stations, among them American, Australian and French. With the aid of the radio, they exchange meteorological reports, consult each

other on various scientific problems and correspond with each other. For more than a year now the Soviet and American expeditions have been exchanging specialists.

At the session of the Antarctic Research Committee of the International Council of Scientific Unions, held in The Hague in February 1958, Soviet scientists supported the U.S. proposal for the prolongation of the International Geophysical Year in Antarctica.

In the messages exchanged by the U.S. and Soviet Governments in May and June 1958, the former raised the question of the Antarctic regime. In its reply, the Soviet Government expressed its satisfaction with the fact that scientists working in Antarctica in accordance with the IGY programme were co-operating fruitfully and signified its readiness to do everything in its power to promote international scientific co-operation in the future too. Such co-operation, the Soviet Government pointed out, should continue to be based on the following principles:

1) Antarctica should not be used by any country for purposes other than peaceful. That means that no military bases should be established there, no naval or air manoeuvres held, and no weapons tested.

2) All governments, organizations and individuals should enjoy equal freedom in carrying out scientific survey in any part of Antarctica.

The Soviet Government further expressed its desire to see these principles sealed by an international treaty ensuring successful long-term development of Antarctic research.

Referring to the territorial claims laid by certain states, the Soviet Government said it did not and could not recognize any separate settlement of these claims. It recalled the outstanding discoveries made in Antarctica by Russian explorers and declared that it was reserving the right, on the basis of the discoveries and surveys made by Russian navigators and scientists, to lay territorial claims regarding Antarctica.

Replying to the U.S. State Department's proposal to convoke an international conference, the Soviet Government agreed to take part in it, provided it discussed the question of using Antarctica for peaceful purposes and of equal freedom in carrying out scientific survey in the area, and in drawing up the draft of the international treaty. But while agreeing to take part in the conference, the Soviet Government pointed out that both the conference and the projected international treaty would be much more effective if they were open to all the states wishing to participate in them.

INDEX OF LITERATURE

1. Авсюк Г. А., Марков К. К., Шумский П. А. «Географические наблюдения в антарктическом оазисе», *Изв. ВГО*, 1956, т. 88, вып. 4, июль—август.
2. Авсюк Г. А., Марков К. К., Шумский П. А. «Холодная пустыня в Антарктиде», *Изв. АН СССР*. Серия географическая, 1956, № 4.
3. Алейнер А. З. «Географические представления об Антарктике», *ИЗВ. ВГО.*, т. 81, вып. 5, 1949 г.
4. Алисов Б. П. *Климатические области зарубежных стран*, Географгиз, М., 1950.
5. Амундсен Роальд. *Южный полюс*, Собрание сочинений, т. 2, Л. 1937.
6. Арсеньев В. А., Земский В. А. *В стране китов и пингвинов*, Изд. МГУ, 1954 г.
7. *Атлас к путешествию капитана Беллинсгаузена в Южном Ледовитом океане и вокруг света в продолжение 1819, 1820 и 1821 годов*, СПб., 1831.
8. Беллинсгаузен Ф. Ф. *Двукратные изыскания в Южном Ледовитом океане и плавание вокруг света в 1819, 1820 и 1821 г.*, Географгиз, М., 1949.
9. Буйницкий В. Х. *Антарктика*, Географгиз, М., 1953.
10. Буркар Х. *Рельеф океанов и морей*, ИЛ, М., 1953.
11. Бурханов В. Ф. *К берегам Антарктиды*, Изд. «Морск. транспорт», М., 1958.
12. Валло К. *Общая география морей*, Учпедгиз, М.—Л., 1948.
13. Гусев А. М. «Первые научные работы в районе южнополярной обсерватории», *Вестник АН СССР*, № 2, 1956.
14. Дарвин Дж. *Приливы*. Госиздат, М.—Л., 1923.
15. Земский В. А. *Звери и птицы Антарктики*, Одесское обл. изд., 1955.
16. Зенкович Б. А. *Киты и китобойный промысел*, Пищепромиздат, М., 1945.
17. Зенкович Б. А. *Вокруг света за китами*, Географгиз, М., 1954.
18. Зубов Н. Н. *Морские воды и льды*, Гидрометеоиздат, М.—Л., 1938.

19. Зубов Н. Н. *Льды Арктики*, Изд. Главсевморпуть, М., 1945.
20. Зубов Н. Н. *Динамическая океанология*, Гидрометеоиздат, М.—Л., 1947.
21. Зубов Н. Н. *О льдах Арктики и Антарктики*. Изд. МГУ, Географ. ф-т, М., 1956.
22. Кидсон Е. «Проблемы метеорологии в Антарктике». В сб. *Некоторые проблемы современной метеорологии*, Гидрометеоиздат, М.—Л., 1937 г.
23. Кирпичников А. А. Тюлени Антарктики и их биологическое значение, *Бюлл. «М. О. И. П.»* Отдел биологии т. 54 (4), 1949.
24. Клепиков В. В. «Ледовые условия плавания в Антарктике в сезон 1949—50 гг.» *Труды ГОИН*, вып. 24., 1954.
25. Лактионов А. Ф. «Льды Антарктических вод», *Проблемы Арктики*, № 4, 1941.
26. Макеров Ю. В. *Антарктика*, ч. II, Гидрометеоиздат, Л., 1956.
27. Марков К. К. *Палеогеография*. Изд. МГУ, Географ. фак-т, М., 1956.
28. *Материалы по лоции Антарктики*, Изд. Гидрограф. упр. ВМС, 1948.
29. *Морской Атлас*, т. 1—2, Изд. Главн. штаба ВМС, 1950—1953.
30. Назаров В. С., Рыбников А. А. «Гидрометеорологические наблюдения на китобойном судне *Слава-15* Антарктической китобойной флотилии в 1951/1952 гг.» *Труды ГОИН*, вып. 25 (37), 1954.
31. Панов Д. Г. «О разделении Антарктики на тектонические области». *Докл. АН СССР*, Нов. сер., т. 78, № 5, 1951.
32. *Последняя экспедиция Р. Скотта*, Географгиз, М., 1955.
33. *Русские мореплаватели*, Воен. Изд. Мин. Обороны СССР, Москва, 1953.
34. *Русские открытия в Антарктике в 1819—1820—1821 годах*, Географиздат, М., 1951 г.
35. *Слава*, Одесское обл. изд., 1952.
36. Соляник А. *«Слава» в Антарктике*, Профиздат, 1954.
37. Таубер Г. М. «Гидрометеорологические наблюдения на китобойной базе «Слава» в Атлантическом секторе Антарктики», *Труды ГОИН*, вып. 14 (26), 1949 г.
38. Таубер Г. М. *Антарктика*, ч. I, Гидрометеоиздат, 1956.
39. Шумский П. А. *Основы структурного ледоведения*, Изд. АН СССР, М., 1955.
40. Щербаков Д. И. «Научные проблемы Антарктики», *Природа*, № 2, 1956.
41. Alexander. *Birds of the Ocean*, New York-London, 1928.
42. Byrd, R. E. "Our Navy Explores Antarctica," *The National Geographic Magazine*, V. XCII, No. 4, October 1947.
43. Byrd R. E. "All-out Assault on Antarctica," *The National Geographic Magazine*, Vol. CX, No. 2, August 1956.

44. Christie, E. W. Hunter. *The Antarctic Problem,* London, 1951.
45. Clifford, M. "The Falkland Islands and Their Dependencies," *The Geographical Journal,* Vol. CXXI, part 4, December, 1955.
46. Cook, James. *A Voyage Towards the South Pole and Round the World,* Lnd., 1777, vols. 1-2
47. Deacon, G. "The Hydrology of the Southern Ocean," *Discovery Reports,* Vol. XV, 1937.
48. Deycon, G.E.R. "The Discovery Investigations in the Southern Ocean," *Trans. Amer. Geophys. Union,* Vol. 36, No. 5, 1955.
49. *Deutsche Antarktische Expedition,* 1938-39, Leipzig, 1942.
50. Dietrich, G. *Die Schwingugssysteme der halb und eintätiger Tiden in den Ozeanen,* Berlin, 1944.
51. Drygalski, E. *Zum Kontinent des eisigen Südens, Berlin,* 1904.
52. Evans, Ed. *British Polar Explorers,* London, 1946.
53. Filchner Wilhelm. *Zum sechsten Erdteil,* Berlin, 1922.
54. Fleming, W.L.S. "Ralic Glacial Forms on the Western Seaboard of Graham Land," *The Geographical Journal,* August, 1940.
55. Flint, R. F. *Glacial Geology and the Pleistocene Epoch,* New York, 1947.
56. Förster, H. A. *Der Hohe Pol,* Leipzig, 1953.
57. Fuchs, V. E. "Trans-Antarctic Expedition, 1955-56." *Polar Record,* Vol. 8, No. 54, September, 1956.
58. Giaever, P. *The White Desert,* the Offic. Account of the Norwegian-British-Swedish Antarctic Expedition, London, 1954.
59. Henry, T. R. *The White Continent,* N. Y., 1950.
60. Herdman, H. P. "The Antarctic Pack-Ice in Winter," *Journal of Glaciology,* Apr., Vol. 2, No. 13, 1953.
61. Hurley, F. Shackleton's Argonauts, Sydney-London, 1948.
62. *Ice Chart of the Southern Hemisphere,* Naval Meteorological Branch, London, 1942.
63. Imbert, Bertrand. *Nouveaux enregistrements de marée en Terre Adélie,* COEC, V année, No. 7, Paris, 1953.
64. "International Geophysical Year 1957/58.—Antarctica, 1956," *Polar Record,* Vol. 8, No. 55, 1957.
65. James, D. *That Frozen Land,* London, 1949.
66. Karte des Antarktis 1:4000 000, Blatt 2, "Petermanns geogr. Mitteilungen," Vol. 98, No. 3, 1954.
67. Kearns, W. H. and Britton B. *The Silent Continent,* New York, 1955.
68. Koopmann, G. *Entstehung und Verbreitung von Divergenzen in der oberflächennahen Wasserbewegung der antarktischen Gewässer,* Hamburg, 1953.
69. Kosack, H. P. *Die Antarktis,* Heidelberg, 1954.
70. Lamb, H. H. and Britton, G. P. "General Atmospheric Circulation and Weather Vibrations in the Antarctic," *The Geographical Journal,* Vol. CXXI, No. 3, 1955.

71. Law, Ph. "The Australian Antarctic Expedition to MacRobertson Land, 1954." *The Geographical Journal*, Vol. CXX, part 4, December, 1954.
72. Liveridge, D. *White Horizon*, London, 1951.
73. Machowski J. *Antarktyca,* Warszawa, 1953.
74. Mackintosh N. A. and Herdman H. F. P. "Distribution of the Pack-Ice in the Southern Ocean," *Discovery Reports*, Vol. XIX, 1940.
75. Mackintosh, N. A. "The Antarctic Convergence and the Distribution of Surface Temperatures in Antarctic Waters," *Discovery Reports*, Vol. XXIII, 1946.
76. Mountevans. *The Desolate Antarctic*, London, 1950.
77. Nychol, J. R. *Stepping Stones to the South Pole,* Sydney-London, 1948.
78. Owen, R. *The Antarctic Ocean*, London, 1948.
79. *Problem of Polar Research*, Am. Geogr. Soc., Sp. publ., No. 7, 1928.
80. Ronne, Finne *Antartic Conquest,* New York, 1949.
81. *Sailing Direction for Antarctica*, Washington, 1942.
82. Scott, R. F. *The Voyage of the "Discovery"*, London, 1905, Vol. I-II.
83. Schytt, V. "Glaciology in Queen Maud Land," *Geogr. Rev.*, Vol. 44 No. 1, Jan. 1954.
84. Shackleton, E. H. *The Heart of the Antarctic*, Lnd., 1909.
85. Scholes, A. *Seventh Continent*, London, 1953.
86. Scholes, A. "Antarctic Air Exploration," *Flight*, Vol. 66, No. 2384, October, 1955.
87. South Polar Chart, Hydrographic Department, London, 1949.
88. Stokes, W. L. "Another Look at the Ice Age," *Science*, No. 3174, 1955.
89. Stommel, H. "The Anatomy of the Atlantic," *Scientific American,* Vol. 92, No. 1, January, New York, 1955.
90. Sverdrup, H. U. *The Currents of the Coast of Queen Maud Land*, Oslo, 1953.
91. Sverdrup, H. U., Johnson, M. W., and Fleming, R. H. *The Oceans, Their Physics, Chemistry and General Biology*, New York, 1940.
92. Svithingbank, Ch. "Ice Shelves," *The Geographical Journal*, Vol. 121, Part 1, September, 1955.
93. *The Antarctic Pilot,* London, 1948.
94. *The Antarctic Today*, Ed. by Simpson, F. A., Sydney, 1952.
95. *The Encyclopaedia Americana*, New York-Chicago, 1951.
96. *The Encyclopaedia Britannica*, Chicago-London-Toronto, 1946.
97. Valton, E. W., Kevin. *Two Years in the Antarctic,* London, 1955.
98. Wade, F. "The Physical Aspects of the Ross Shelf Ice." *Proc. Am. Phil. Soc.*, Vol. 89, No. 1, 1945.
99. Wordie, J. M. and Kemp, S. "Observation on Certain Antarctic Icebergs," *The Geographical Journal*, Vol. 81, No. 5, London, 1953.
100. Wright, C. S. and Pristley, R. E. *Glaciology, British Antarctic Expedition 1910-13*, London, 1922.

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В. ЛЕБЕДЕВ

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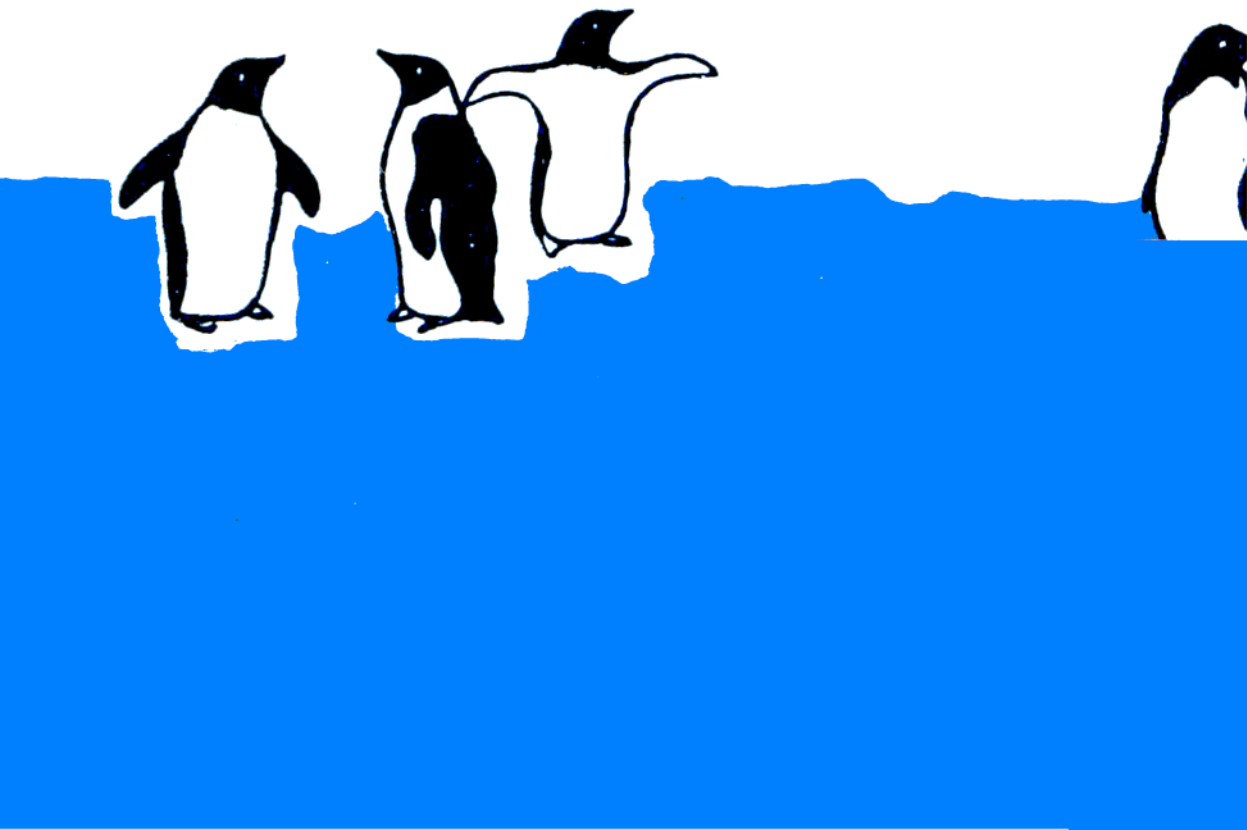
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